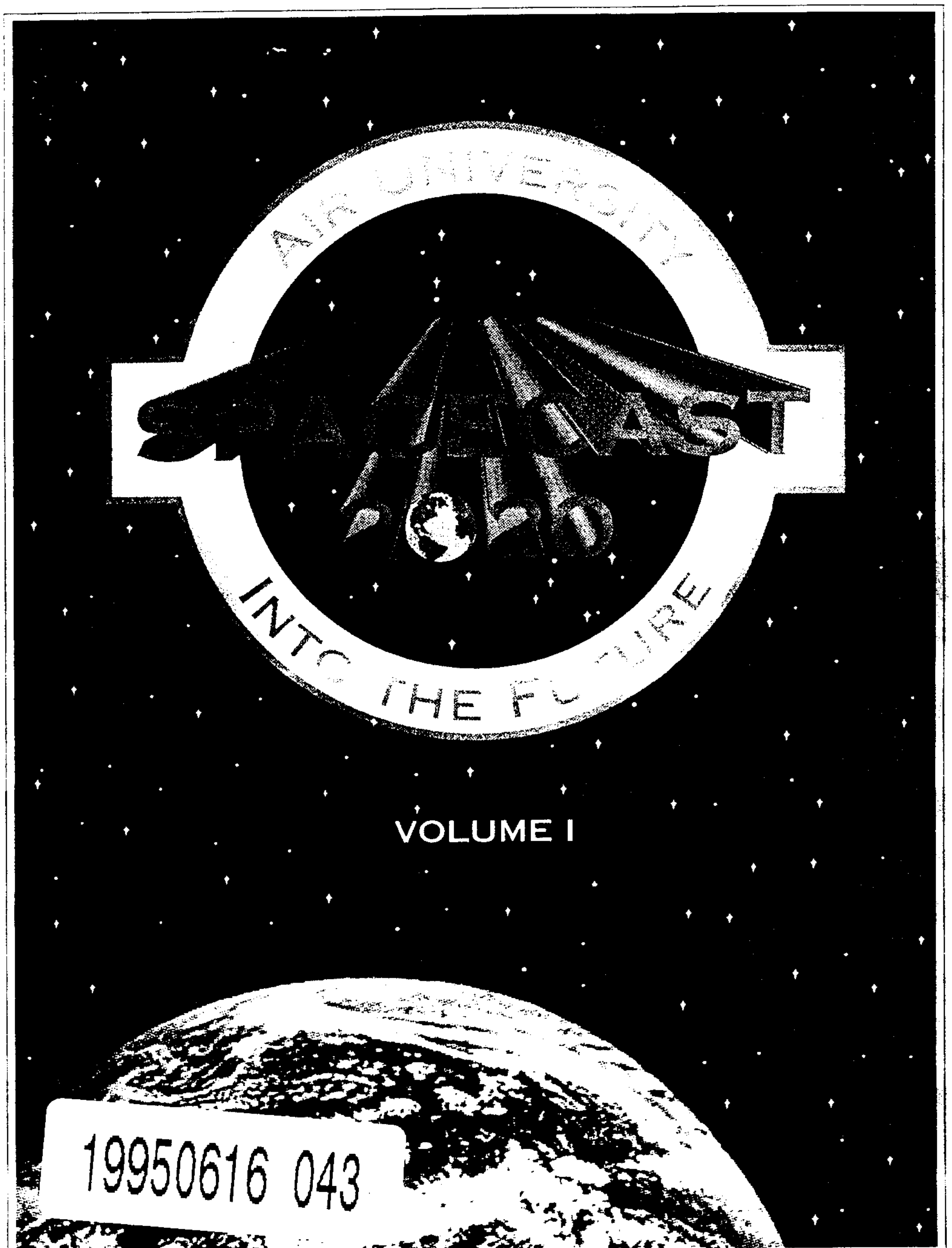
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SPACECAST 2020 was a Chief of Staff of the Air Force (CSAF)-directed space study, challenged to identify and conceptually develop high-leverage space technologies and systems that will best support the warfighter in the twenty-first century. The study produced a series of white papers which have been assembled into clusters of concern for future space capabilities. Volume I consists of 11 unclassified white papers: Leveraging the Infosphere: Surveillance and Reconnaissance in 2020; Space Traffic Control: The Culmination of Improved Spave Operations; 21st Century Weather Support Architecture; Space-Based Solar Monitoring and Alert Satellite System; Space Weather Support for Communications; Spacelift: Suborbital, Earth to Orbit, and On Orbit; Unconventional Spacelift; Rapid Space Force Reconstitution (RASFOR); Space Modular Systems; Professional Military Education (PME) in 2020; and Preparing for Planetary Defense: Detection and Interception of Asteroids on Collision Course with Earth. The Volume also contains an Operational Analysis and listings of Project Contributors and Project Participants.

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SPACECAST 2020

Volume I

Prepared by the Students and Faculty of

AIR UNIVERSITY

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Air Education and Training Command
United States Air Force
Maxwell Air Force Base, Alabama 36112-6428

June 1994

DISCLAIMER

A study done in compliance with a directive from the CSAF to examine the capabilities and technologies for 2020 and beyond to preserve the security of the US. Presented on 22 June 1994, this report was produced in the Department of Defense school environment in the interest of academic freedom and the advancement of national defense-related concepts. The views expressed in this report are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States government.

Volume I

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FOREWORD

Perhaps the oldest military maxim concerns the advantages of holding and using the high ground. The high ground has always provided tremendous advantages in vision and extraordinary leverage in force employment. When mankind soared into the air, the concept of holding and using the high ground took on an entirely new dimension, and air power revolutionized the conduct of warfare.

Now, in the latter years of the twentieth century, mankind is making its way beyond the limitations of the atmosphere and into the ultimate high ground of space. It follows that the ability to operate in and through space has the potential to revolutionize yet again the conduct of warfare. But, this potential will only be realized with imaginative forward thinking that breaks the ties binding our minds to the concepts of the present.

In May 1993, the United States Air Force Chief of Staff, General Merrill A. McPeak, challenged the faculty and students of Air University to break the bonds of the present and envision the possibilities, capabilities, and technologies the United States will require to exploit the space high ground in pursuit of national security objectives. SPACECAST 2020 is the result of that challenge.

SPACECAST 2020 makes clear the two paramount military advantages of space--unparalleled perspective and very rapid access to the Earth's surface. Exploitation of these advantages could have a major impact on intelligence, communications, command and control, navigation, force application and many other critical aspects of military operations. Further, the ability to "see over the next hill," as the Duke of Wellington might have put it, can significantly reduce uncertainty and insecurity and thus promote stability.

SPACECAST 2020 also makes clear that to fully exploit the advantages of the ultimate high ground, the United States must pursue a significant number of high-leverage technological capabilities. They range from capabilities that are already needed, such as reusable lift, to those capabilities that are only on the mental horizons of the most ardent futurists, such as defense of the planet earth against asteroids in earth-intersecting orbits.

The hundreds of participants in SPACECAST 2020 rose to General McPeak's challenge. They produced a document of imagination and foresight. They identified many of the capabilities we will need and many of the technologies we must pursue. I believe their final report, which you have in your hands, is well worth reading.

JAY W. KELLEY
Lieutenant General, USAF
Commander, Air University

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INTRODUCTION AND OVERVIEW

INTRODUCTION

The investigation of emerging technologies for space in the year 2020 and beyond is of paramount importance to the United States. Lead times for advanced terrestrial and atmospheric weapons systems can take as long as 20 years from the initial requirement to operational capability. For projects involving complex technologies, new concepts and materials, or unfamiliar environments, a quarter century seems a minimum planning horizon. In the competitive world in which we live, the failure to investigate such issues in 1994 could imperil national security in 2020.

In May 1993, the chief of staff of the United States Air Force directed Air University to undertake a study to identify capabilities for the period of 2020 and beyond and the technologies to enable them which will best support preserving the security of the United States. The study team considered the full vertical dimension, including the important region of the transatmosphere that both separates and integrates air and space. This 10-month long effort became known as SPACECAST 2020. The study methodology was distinctive in several respects. It

1) involved faculty and class members at the Air Command and Staff College and the Air War College at Air University, Maxwell AFB, AL;

2) depended on the scientists and technologists at the Air Force Institute of Technology, Wright-Patterson AFB, OH, to solicit, provide, and evaluate emerging technologies and creative applications;

3) was not limited to experts in one field or specialty. Instead, personnel with vastly different career backgrounds and educational specialties participated in the study, the majority of whom were from the operational line forces of all the services;

4) included the assistance of members of numerous other government agencies, universities, laboratories, think tanks, and inputs from a worldwide data call;

5) utilized high technology means to collect, analyze, synthesize, and deploy information through video conferencing, computer data bases, and specially devised software;

6) was consistently validated internally through a two-team system of Creative Activity Teams (CAT) and a Realistic Assessment Team (RAT), and externally by an Expanded Realistic Assessment Team (ExRAT) of scientists and technologists, an Executive Board, and a Senior Advisory Group, each of which reviewed each step of the process as it was being accomplished and validated all the major findings;

7) envisioned the idea of "Global View" through "users"--not scientists;

8) created a large, network of scholars, analysts, creative thinkers, and operators who became partners in the study;

9) produced over 100 officers with an expanded awareness of the national security challenges of the far future and the ways space operations can contribute to meeting these challenges.

Quite simply, the SPACECAST 2020 study "stirred the pot" and produced some new ideas.

As the product of a creative but disciplined process executed by operators, the findings present a range of possibilities designed to stimulate the thinking of experts. Some findings fail the test of expert validation. The implementation of others will be constrained by resources or the need to invest in urgent, near term requirements. Still other ideas will prove to be constrained by treaty or agreement. SPACECAST's goal was to energize thinking and imagination to produce a set of possibilities refined and integrated so that senior leadership could adopt all, some, or none of its major ideas. They could select any of these ideas with reasonable confidence that they are important issues that the US must address if it is to play a dominant role in space in the twenty-first century.

SPACECAST 2020 was done at marginal cost, with virtually free analytic and creative effort from over 350 people who represented both the operational communities from all the armed services and some of the best scientific and conceptual talent available. It was unconstrained, the only major injunction being to remain detached from

the roles and missions debate. It produced a series of white papers which have been assembled into clusters of concern for future space capabilities. Of all the findings of SPACECAST 2020, none is more compelling than the observation that robust space operations are critical to the security of our nation.

More Than A Place

Space has been called many things by many people--the ultimate high ground, the last dimension of warfare, the high frontier, and the final frontier. **Space is all these and more**. Its most fundamental characteristic from a military perspective is that it possesses unprecedented vantage or view. It answers the age-old wish of military commanders to be able to see the other side of the hill. Variously defined in the past as both a place and a mission, space is also a laboratory of the unknown; a potential area for commercial exploitation; a medium in which surveillance, communication, navigation, and transit are now routine; and an arena of increasing cooperation, competition, and potential conflict.

We are in space regularly. Space has been used for military purposes for nearly four decades. A highly public, technological space race with the Soviet Union characterized a dozen years of the cold war from the launching of Sputnik in 1957 to the landing of Americans on the moon in 1969. During the cold war a source of pride to the citizens of the United States was that we had walked on the moon while others had ventured only a few hundred miles beyond the surface of our planet. The cold war is over, but competition and conflict are not. New relationships are developing and new patterns of both competition and cooperation are emerging. Space offers opportunities for friendships and partnerships to grow.

Even so, national accomplishments in space are and will remain a barometer of international status and prestige, technological prowess and military capability, whether we like it or not. Countries as diverse as Israel and China, Brazil and Pakistan, Japan and Argentina all have interests and assets in space. If the United States seeks to continue to be a great power, let alone the world's only superpower, it must maintain a dominant presence and capability in space. Not to do so may appear to be an abdication of power in the eyes of countries whose capabilities in space are growing. There are things we may do unilaterally in space that have global benefit such as navigation, weather and communication.

Maintaining a space capability is difficult, expensive, and fraught with risk. Our country must invest its limited resources wisely. Selecting the most promising technologies is critical to this venture. Only those states who have the capacity to have an impact on *why* and *how* space is utilized will play a role in shaping the environment of space. **If we want to maintain or increase our presence in space, we must pay the price to do so.** If not, we could cease to enjoy our current status, deference, and power. This study assumes that we will continue a conscious commitment to being a major actor in space.

Why does the US need to be a space-faring nation? What is it that can be done in space that can't be done elsewhere? **The single most important reason to be in space is to acquire "Global View."** Transformations of technology, the geo-political environment, military dispositions, and capabilities of other states and nonstate actors are all critical information if the US is to maintain its own security and that of many other states dependent on this knowledge. Presence in space to collect, analyze, synthesize, and disseminate information rapidly is vital if we hope to continue to be able to attempt to shape the international environment and preserve not only national but international security.

Before one can respond to changes, one has to know that things have changed. Knowing, raw knowledge, is inherently worthy. The knowledge that can be gained from the vantage of space about the globe enables us to increase the quantity, quality and speed with which information can be utilized. The variety of knowledge and rapidity with which it can be disseminated and utilized makes space critical to successful competition, both public and private, in the twenty-first century.

Global View is the enabler for Global Reach, Global Power. There are several reasons for this. (1) <u>Knowing</u> what is transpiring in near-real time is a tremendous advantage for effectively maintaining security--a prerequisite for anything else. (2) More importantly, having others know that we can know what is occurring creates a powerful deterrent for hostile action. Such <u>deterrent capability</u> adds to the value of the knowledge itself. (3) Space-based sensors create <u>presence</u> which can in many cases, but not all, substitute for forward deployments of military forces. This can diminish the logistical problems of transportation and sustainment and the risk of human lives. (4) Should conflict become a reality, the capacity to combat adversary forces by using our superior knowledge and information derived from space-based sensors and communicated by

space systems enables new methods for the warfighter to use to engage opponents. (5) The quantity and quality of information that can be gained from space-based vantages enhances the power of existing terrestrial forces, both conventional and unconventional, by providing more and better information more rapidly. Space allows you to see the other side of all hills. It is the only real way to come to grips with dispersed threats, distributed capabilities, and disparate data points. There are today and there must always be effective terrestrial means for creating global reach and global power. **Space is the only vantage point from which to attain Global View.**

Technology and the Pace of Change

SPACECAST 2020 does not pretend to provide the vision of the future. The world in which we live is chaotic, filled with constantly changing, unknown and unknowable challenges and opportunities. The planet's political, economic, and social instability is a general condition, not always or even necessarily a threat. Attempting to predict with certainty exactly how events and capabilities will unfold in an unstable world is a fool's errand. We cannot know in detail what the future holds. We can, however, speculate in an informed fashion on the technologies that would be of most value and which are not beyond plausibility. We can also assess the relative merits and demerits of certain capabilities, consider the trade-offs among various investments and their returns, and identify the show-stoppers, the items without which we simply cannot progress further. Technological progress is one whose history has proven to be uneven, nonlinear and irregular and promises to be even more so in the future given the pace of change.

There are essentially three different types of technologies. The first type is rapidly emerging, fast-track technology, characteristic of industry and the private sector, evident in areas such as commercial electronics, communications, and computers. The second type of technology has had great investment in the past, but this interest is slowing appreciably or stalled because of the end of the cold war. These were hybrid, public and private ventures, supporting such items as secure and survivable communications, sensors and some basic research useful to the private sector largely because of large government investment and the possibility of commercial spin-offs. The third type is so complex, expensive, and slow in development that only governments who have sufficient need and resources can invest in them. This type generally has no immediate visible civilian applications. Large-scale weapons systems and space lift are examples.

The process of transforming technology into national security capability requires awareness of the three categories of technology emerging in the post-cold war world. To assimilate technology into systems providing national security capability, three separate approaches need to be integrated. First, the armed forces need to remain aware of the rapid advances occurring in computers, communications and electronics and "spin-on" to those developments that can expand national security capabilities. Second, the armed forces need to expand partnerships and contribute to basic research and technology development in all those areas essential to future national security capability. This is the most challenging area because it demands a clear vision of long-range goals and an understanding of future needs never before required. Third, and finally, there is a category of technology where we simply must accept that we are obliged to take the lead. The development of weapons, and affordable space transportation, falls in this category.

Implementing the concept of Global View as a reality depends on three things: an integrated, on-demand information system; increased and improved sensing capabilities, and, relatively inexpensive space lift. Having a capacity to utilize an integrated, on-demand information structure in space would reap the greatest benefits. The US has considerable sensing capability, but nothing like what is likely to emerge in the next 30 years. Such a system would empower global vision more fully. None of this is routinely feasible, though possible, without improved lift. Specifically, we must attain a capacity for responsive, flexible, resilient, and most importantly, relatively inexpensive lift. Lift is the basic enabling capability for what is built on top of it. The lack of inexpensive lift will severely limit our abilities.

There are many factors that can affect how we proceed in the future. These factors include the availability of financial resources, the overall state of the economy over decade-long spans of time, the differential rates of technological advancement, political leadership, and decisions on relative priorities on the national agenda. These factors make predictions about the unfolding of future technologies and their interaction difficult. Still, there are some certainties. Consumer technologies will achieve rapid and continuous progress because of the commercial incentives for their advancement. Other joint use technologies that are stalled at the moment may or may not progress. Massive, publicly funded technologies for weapons systems and space lift may be impossible absent a truly significant threat or awareness of clear benefit to the public. First among

these in importance is an information architecture that can function on-demand to provide access to information for us and provide it or deny it to others.

"Demand" information systems differ from "command" systems. Command systems evolved to support strictly hierarchical military organizational structures in an era when the cost of bandwidth was high, when data processing required large, fixed mainframes, and when the principal threat to our national security largely was restricted to a single geographical area. Command is top down. Demand is bottom up. The field commander should be able to "pull down" the information desired instead of only being provided information "pushed down" via the command of others. The cost of bandwidth is now lower, even becoming inexpensive, the computational capacity of small, portable computers continues to increase, and military forces are reorganizing to cope with a world of distributed dangers and unexpected, rapidly arising threat possibilities.

These developments allow, and SPACECAST believes require, the creation of a demand information architecture. The architecture for such a system is the novelty; the technology will emerge largely from the private sector because this technology has commercial incentive and application. Global cellular communications and exponential improvements in computing will become realities without government financial participation because of commercial demand and profitability. Without such continued progress, the notion of Global View will not happen. The communications and computer technologies required are ones which we have reasonable confidence will be extant by 2020, if not well before. The types of technologies and capabilities made possible by them in an integrated on-demand information architecture are the essence of the requirement for Global View.

Acquisition of the type of sophisticated, integrated, multispectral sensors which may make the knowledge possibilities inherent in global view a reality are more costly, more difficult, and less predictable. They may or may not evolve smoothly and they will be the product of public and private co-sponsorship and joint development. While characterized by opportunities for dual civilian and military use, these sensors are costly and depend on certain breakthroughs to become an operational reality. They will require large amounts of funding from both sectors and will have spin-offs, spin-ons, and future opportunities for both partners in the development and application of such technologies. The sensors are the input mechanisms by which the information architecture functions and are hence the enabling technologies required to realize this vision.

All of this depends on space lift and space lift depends on the government. Innovation in space lift--the introduction of a less expensive or reusable vehicle--requires government leadership and public funding, long-term commitments to extensive research and development, continued refinement through different generations of capabilities and high priority support. Unless or until we solve the problem of expensive space lift, we can operate in space using other technologies, but only in a halting and incomplete manner. Inexpensive space lift is the enabling element which makes the other aspects a reality. Without it, we can continue to function with the existing alternatives. However, acquiring inexpensive or reusable lift would greatly enhance the opportunities and capabilities in space. Though not a prerequisite because there **are** alternative launch vehicles in the inventory for the next dozen years, a low-cost and responsive space lift would reap untold benefits. **Without government support on a large scale, it is not likely that less expensive, resilient, reliable, and flexible space lift will become a reality.**

OVERVIEW

The following is a set of creative concepts, emerging technologies, and potential capabilities which can enable the US to become a space-faring nation in the twenty-first century. They are not engineering studies, requests for proposals, or fully articulated designs for new systems. They are first cuts at giving substance to the concepts generated from assessing alternative solutions to difficult problems in a complex future world. They are informed conjectures about how we might best plan for our future in space. Taken collectively, they offer suggestions for an investment in the protection of US interests and assets in space in the far future. Some are possible to pursue right now after validation by experts. Others may prove to be impossible. Taken individually, they offer an array of choices, large and small, for investing in a significant arena of global interaction in the twenty-first century.

These concepts are divided into several different categories. The categories represent clusters of functional areas of space activities. If the US is to become a viable actor in shaping the arena of space as the larger adjunct to global security interests, it must develop competence in these areas. These areas or categories of activity are

- ***GLOBAL VIEW***

- ***GLOBAL REACH***

- ***GLOBAL POWER***

Taken collectively, these provide the capabilities for accomplishing what we believe will be the military mission. Technological advancements exist today with varying degrees of future promise which make possible a new kind of national and international security in the twenty-first century. The United States must not only be able to be in space, it must be able to act from space and to protect space-based assets. How?

GLOBAL VIEW

Taking advantage of the opportunities provided by the vantage of space is first and is best done by observing what is happening both on earth and in space from space. The observation and orientation capability afforded by space gives us **Global View.** Knowing the disposition of forces is a requisite for any military commander and space based assets give unprecedented capability to do this. The need to know about our adversaries, our allies, and ourselves is greatly enhanced, as is the response time in which we can make decisions in both war and peace, by space operations aimed at monitoring and reporting. **Having friend and foe alike know that we know what is happening is a deterrent capability of immense proportions**. The ability to have access, influence, and control over information is a significant capability enhanced by space-based assets.

Similarly, **an inability** to exploit the vantage of space for acquiring information would introduce significant uncertainties and seriously hamper our capability to compete both in space and on the earth. The consequences of us <u>not</u> knowing critical information and an adversary possessing such a capability could deter the United States from action or winning a contest of arms. The capabilities listed here under Global View, while passive in a sense, are the essence of the successful use of space at the moment. They include such elements as surveillance, reconnaissance, exploration, environmental sensing, information collection, research, intelligence, navigation, command and control, and communication. The near-real-time capability in all these areas offered by the proper utilization of space and the opportunities it presents make this area of concern critical to the successful exploitation and control of space.

By 2020 there will be so much information to collect, analyze, assess, synthesize, and disseminate that the quantity will present a challenge of such magnitude as to be

almost incomprehensible. There will be a virtual explosion of information, an exponential growth so dense and constantly expanding that we must envision an information sphere which surrounds us in space as the atmosphere does on the earth. Constructing an information architecture to selectively capture, process, and use information is a critical priority. The fusion of relevant data will require a major expenditure of time, money, and effort, but is mandatory to cope with both the problems and the opportunities we will encounter in 2020 and beyond. Command systems are inadequate to cope with the demands for information that combatant forces and other users levy. To be truly effective, information should be provided when requested by the user, not merely when offered by the provider. Demand systems are required.

In the "infosphere" of 2020, knowing the adversary and knowing yourself will unquestionably be essential for success, but may not ensure it. The temporal dimension of a decision cycle will be as important as the information that feeds it. The one that knows and can act on information first will be the side that has a distinct advantage. Space offers great advantages in both timeliness and availability of information for decision-making. Such fundamental characteristics of space as vantage point and speed that make it useful today must be further exploited to provide users of 2020 the ability to sense greater portions of the earth more rapidly, communicate more effectively, and decide more quickly what action to take. This section of the SPACECAST study proposes an integrated demand architecture for Global View and examines the areas of surveillance and reconnaissance, navigation, space traffic control, and weather that can capitalize on the characteristics of space to support the needs of national security in 2020.

The following provides a brief synopsis of the papers in the full report:

The paper titled **Global View: An Information Demand System for the Joint Warfighter of Tomorrow** presents a proposal for a design and a phased approach for building a demand information system on present capabilities to satisfy the needs for on demand near-real-time global access to all available information relevant to the mission. This information would consist of both raw and processed data and be available to battlestaffs, weapons systems personnel, and forces all the way down to the soldier at the platoon level. The architecture envisions interactive mass data base storage, on-board and on-line interactive distributed processing, and queuing and query capabilities to enable both selective command dissemination and on-demand access to time-sensitive information directly by the user. It is the blueprint for combining separate systems and

architectures into an integrated and interactive architecture. This paper outlines an evolutionary transition to achieve revolutionary capabilities.

Leveraging the Infosphere: Surveillance and Reconnaissance in 2020 proposes concepts that use ground and space-based systems incorporating hyperspectral and other imaging and sensing technologies to detect and provide real-time, fused information of all types to the user. This concept combines conventional sensing techniques (by 2020, routine sensing techniques) such as imagery, signals, laser, radar, and so forth with new advances in high-resolution, remote surveillance and hyperspectral sensing in acoustic, seismic, olfactory, and gustatory areas. Data from all sensory inputs are used to identify objects by comparing their structural sensory signature with existing data bases. These "omnispectral" and "omnisensorial" capabilities, diligently pursued and implemented, will be essential to "knowing" in the twenty-first century. Knowing is as essential to finding the lost child or the leaking fuel line as it is to prosecuting military operations economically and effectively. The wealth of ideas outlined, including opportunities for breakthroughs in signature detection and identification, show how the vantage of space can be used.

Navigation and Data Fusion for the 21st Century examines the concept of a Super Global Positioning System (S-GPS) providing three-dimensional navigation capabilities, and shows how it can be fully integrated into real-time battle management and dissemination to all levels of authorized users. Super-GPS increases current GPS capability, refines its accuracy, and effectively fuses it with other sensor information including navigation, geographic spectral imaging, and weather. The system uses on-board processing and fusion to provide near-real-time information availability on demand. It explores the concept of "pay-per-view" type algorithms, codes, and keys to control civilian users' access as well as resolve information distribution challenges in dynamic environments. It asserts that the tremendous advantages already provided by a space-based navigation constellation can be made even more robust, secure, precise and widely available by 2020.

Just as we had to develop "airways" for an expanded number of planes flying in the atmosphere, we will need a means to track and control transatmospheric and space flight as the use of space increases. As the boundaries between space and atmospheric travel become less distinct and as the environment of space becomes increasingly crowded, there will be a growing need for tracking and traffic control of space objects

and vehicles. **Space Traffic Control: The Culmination of Improved Space Operations** describes a system employing space-based sensors to provide continuous, in-flight deconfliction of orbital space systems without operator manipulation. Under this concept, space operators in the future would have a system into which they could enter a space or transatmospheric flight plan and automatically receive preliminary deconfliction clearance on a "spaceway." A key theme in the design of this system will be increased satellite autonomy to include navigation and housekeeping functions, as well as new techniques for tracking and controlling the activities of systems in space or transiting space. The belief that space power will evolve along lines similar to air power is unremarkable in itself. The vision that asserts concrete ways to build and control spaceways is remarkable and a prerequisite for safely expanding the routine transit of space in the far future.

Weather conditions will continue to have a significant impact on many aspects of life on our planet, including military mission accomplishment. Timely knowledge of potential weather impacts can enhance decision-making capabilities at all levels. Warfighters will need near instantaneous, worldwide access to current and forecast weather conditions for a given point or area in time and space. **21st Century Weather Support Architecture** examines options in accessing integrated weather information in 2020 and an architecture to provide tailored weather data and forecast products directly to the military and civilian end users via the information superhighway. Until humankind is able to exert more control over the natural environment, the ability to know that environment is the dominant task. By the twenty-first century, knowing the weather on earth must be augmented by knowing the weather in space.

Space operations are in constant jeopardy of mission degradation or failure because of space weather. Capability to provide space weather forecasts and hazard alert warnings will become increasingly important as space use increases. **Space-Based Solar Monitoring and Alert Satellite System** proposes a satellite monitoring and alert system in deep space that will continuously observe the solar atmosphere and monitor solar plasma emissions, or solar wind. The system consists of multispectral sensors with on-board analysis capability to provide near-real-time space radiation hazard warnings and forecasts of radiation impact to an operations center on earth or in space for protection of satellite resources and space operations. Commercial users need this service, and this paper argues that it is a government's obligation to help provide it.

Communication and interconnectivity of other monitoring and reporting assets will be critical to sustaining the infosphere of the national security forces of 2020. Ionospheric variability, an attribute of space weather caused by solar radiation, significantly impacts ground and space-based communications. **Space Weather Support for Communications** reviews enhanced ionospheric sensing capabilities to predict and provide warning of potential communications, radar, and navigation disruption or blackout. The concept envisions deploying ionospheric sensing devices on present and future GPS and follow-on commercial satellite constellations to obtain daily, world-wide mapping of the ionosphere.

Each of these concepts can make major contributions to meeting the broad range of information needs of combatants and national decision makers in achieving national security objectives in 2020. They fuse relevant information in the continuous cycle of observation-orientation-decision making-action to create near-real-time capabilities to observe, orient, decide, and act in important areas of activity. These concepts leverage innovative application of technology developments forecast for 2020 with the inherent vantage and speed afforded by space to meet these needs. Failure to develop, deploy, and utilize such opportunities would likely cripple the United States' ability to successfully deter future conflicts or meet our objectives efficiently and effectively in those cases where conflict cannot be prevented.

GLOBAL REACH

This section addresses those things it takes to reach into space: the lift, support, and education and training aspects of space in 2020. The papers address the ability to access space and, once in space, the capability to maintain a ready, national security presence. The implications that technological advancement and enhanced space presence will have on our education and training processes are also examined. All are aspects of truly Global Reach.

The United States must have assured access to space to deter adversaries and protect the US, its allies, and intergovernmental organizations promoting regional and global security. This means placing payloads into earth orbits with high reliability, quickly and responsively, affordably, and with great resiliency (or the ability to recover rapidly from a launch or mission payload failure) even if these systems come under attack. Our current space lift capability is certainly inadequate against these criteria. National imperatives dictate developing a lift capability that will enhance our interests

while allowing profit-motivated commercial exploitation and a near seamless integration of space with air.

There are few papers in the Global Reach section. Of the 15 SPACECAST teams organized to generate and refine concepts for new capabilities, only one was dedicated to spacelift. The other 14 were told to presume that inexpensive lift was available by 2020. An authoritative and high level launch modernization study was underway at the time and it was the responsibility of that study to respond to the near and mid-term the challenges of launch. But just in case that effort was unable to do so, the one SPACECAST team was directed to be as creative as possible while also emphasizing our present strengths. The SPACECAST effort developed the operational concept for an air refuelable transatmospheric vehicle originated in the Air Force's Phillips Laboratory.

Spacelift: Suborbital, Earth to Orbit, and On Orbit presents a vision of a composite aerospace wing which includes a squadron of rocket-powered transatmospheric vehicles (TAV). As envisioned, these fighter-sized airframes would be capable of placing approximately 5,000 pounds in any low earth orbit or delivering an equivalent payload to a suborbital trajectory to any point in the world. The concept would entail aerial noncryogenic propellant transfer from modified KC-135Q aircraft and maintenance, logistics, and ground operations compatibility with the rest of the aircraft wing. Although an experimental prototype, an X-program vehicle (nicknamed *"Question Mark 2"* in honor of the first air-refueled aircraft), may be available well before 2020, test and development is urged now. Proof of concept before the turn of the century would allow TAVs to be available in significant numbers by the year 2020. Transatmospheric vehicles, developed in partnership with commercial aviation, shrink the planet and integrate air and space.

Unconventional Spacelift grew from a mandate to AFIT to explore creative solutions and far future opportunities for unconventional approaches to space lift. How would we get into space using means that did not rely on traditional rocket propellants? The question triggered nearly 80 responses. Narrowing the field from 80 proposals to a handful, the paper asserts the need to explore low earth orbiting tethers, geostationary tethers and "space elevators," metastable fuels, nuclear propulsion and even anti-matter systems. Visionary today, one or more of these may provide the breakthrough that makes space access truly routine and commonplace tomorrow. We found, however, no "silver bullet" solutions.

Rapid Space Force Reconstitution is an essential element for military space operations. A change in the way we think about satellite design and launch could lead to more responsive systems and more rapid reconstitution in a crisis. Small satellite and boosters designed for responsiveness could offer the best opportunity to access space in an emergency. It is the traditional obligation of the military to be prepared to succeed, even in emergencies. Some compelling criteria for lift systems and satellite design postulated in the paper are that they be able to reconstitute lost space capabilities rapidly and with the highest reliability. Arguments for this approach to lift system and satellite design are discussed in this paper, an earlier version of which was selected by the commander in chief of the United States Space Command as the winning military space strategy essay of 1994. Its precepts and arguments can, and should be challenged, but some of the concepts it outlines deserve closer scrutiny than they may have received to date.

Full exploitation of space requires a capability to sustain operations in a timely and effective manner. Many of today's satellites are large, complex, redundant, expensive, and cannot be upgraded or repaired except at extraordinary cost and under special circumstances. **Space Modular Systems** and common satellite interfaces complement the TAV lift concept of ready space access with smaller payloads. In this concept, a large satellite will serve as a motherboard to space modules by providing inclusive support of power, communications, and housekeeping. The modules will be small with each having distinct missions or functional capabilities ranging from imagery to communications and will be lifted individually to the motherboard. The modules and motherboard will be mated via common satellite interfaces. These modular payloads will be less complex, upgradable, and will provide national security decision makers and forces a responsive space capability. Physical connectivity to the motherboard is a beginning, replaced eventually by proliferated and distributed modules that are "virtually" or electronically connected as technology allows. The idea of small, distributed and proliferated systems is central to most of the SPACECAST papers.

An on-orbit space depot could provide the logistical support for the motherboards and their modules. In addition to depot functions the station would provide satellite refueling and debris removal. Servicing would be accomplished either through satellite retrieval or on-location servicing of satellites distant from the depot. These functions would be accomplished with orbit transfer vehicles (OTV) and orbital maneuvering vehicles (OMV). If a permanent human presence becomes a goal, provisions could also

be made for a manned orbiting industrial park. Beginning as a "bare base" with the organic essentials of gravity, power, water, air, food, and fuel, such a facility could grow to allow industrial processes to synergize with the benefits of the space environment and permit spin-offs into other areas. Even so, and except for routine transit of space by humans flying TAVs, an unexpected finding of SPACECAST is that the *need* for humans in space will be marginal even until the middle of the next century. Advances in high performance computing, robotics and end-effectors, and micro-mechanical devices are envisioned as substitutes that satisfy the need for human presence. This is not an assertion that human presence in space should not increase. It is merely a description of the operating environment of 2020 as SPACECAST participants envisioned it.

Understanding is a prerequisite to doing. Hence, future space education, training, and technological enhancement of educational approaches is mandatory. As our nation extends beyond its terrestrial borders, our personnel must be educated and trained in space concepts. **Professional Military Education (PME) in 2020** provides this vision. It argues that information technology now provides the opportunity and means to change the education and training paradigm for military personnel. Compared with an ambitious view of what may be possible, today's professional military education system is episodic, requires the physical presence and movement of people to and from the site of the university, and cannot offer greatly expanded opportunities for performance-enhancing enrollment. By 2020, or well before, information technology will allow for the creation of a learning environment that is continuous, less costly, made available to the entire force, and characterized by personal networking. The model for a new approach to professional military education could be used by universities and technical training schools, both public and private, and be modified for both resident and distance learning environments.

Global Reach, broadly defined, will eventually grow to the degree that it requires a larger presence in space to be done effectively and efficiently. The military may well become less reliant on its own organic capabilities for training, research, development, and sustainment. Knowing that, commercial enterprises can become involved earlier and begin offering their services sooner. If they do, by 2020, ours truly will be a space faring nation on a basis that seems almost unimaginable today. Doing so will not be easy but it will provide vastly increased opportunities. Both the public and private sectors can gain from the vantage offered by space presence.

GLOBAL POWER

Counterforce operations are those space or transatmospheric activities aimed at opposing or defending against threatening force anywhere on the planet or in space. This threatening force may arise intentionally as the product of hostile human will or it may exist naturally. By 2020, space operations could be aimed at countering both kinds of threatening force in order to truly achieve Global Power. Our understanding of space power, and with it our lexicon, must grow to embrace powerful new ideas. Just as a Global View is essential to a Global Reach, authentic Global Power requires both vision and reach.

The United States must have the capability to protect what it values. Global power helps to provide the required protection. We may also deter marginal powers and some space faring adversaries from hostile acts both in space and on the earth's surface. This paper examines various applications of Global Power beginning with the traditional areas of defensive counterspace operations, offensive counterspace operations, and force application. In addition, the contributions that information power and microscale weather control can make are also examined. Lastly, there is an analysis of the issue of detecting and protecting the earth against asteroids that could intersect the earth's orbit.

Space forces have contributed to national security for nearly four decades. **The tremendous costs of these systems are often offset by their even greater value.** In the future, space systems can evolve to further complement and potentially replace many of the traditional elements of terrestrial forces. Indeed, the rapid development and assimilation of the capabilities proposed could fundamentally transform the character of military forces and the nature of military operations. The line-of-sight and energy advantages of space continue to offer tremendous opportunities for national security.

During Operation Desert Storm, American and Allied forces relied heavily on space-based systems for navigation, weather information, secure communications, and surveillance support. These and other space assets played a key role in the successful prosecution of the Gulf War. As a result of the reliance on these and the associated success, our reliance on them will only increase. Therefore, these systems will present attractive targets for the enemy and their protection will be a critical consideration in the future.

The **Defensive Counterspace** section examines a force protection platform concept as a creative potential solution to this problem of system survivability. The concept involves the development of a series of satellites designed primarily to protect high-value orbital systems. These satellites could escort the high-value orbital systems and provide protection to inhibit an adversary's ability to detect, identify, track, or destroy our space assets. They thus provide a range of active and passive countermeasures to protect US space assets.

Potential adversaries increasingly will depend on space-based assets to be their eyes and ears on the battlefield for the reception and delivery of information. Presently, the United States has the ability to negate access to some of this information only through diplomacy or earth-bound application of force. We do not have the ability to control adversarial space-based assets. **This could cost many American lives in future conflicts**. To make the adversary blind and deaf on the battlefield and allow our forces to operate inside the decision cycle of the opposition, we must take the initiative to develop the capability to control an adversary's space assets or eliminate them when and where necessary.

The **Offensive Counterspace: Achieving Space Supremacy** section describes a future space-based system that could provide timely control and exploitation of an enemy's space-based assets. This proposed system would incorporate a variety of technologies to influence enemy satellite capability. The section also describes creative methods of reducing the system's visibility to hostile sensors and maximizing its rapid deployment against any adversary's on-orbit assets. The ability to deny useful information from space-based assets to an enemy will be a key to meeting our objectives in any future conflict.

The **Force Application** section proposes various concepts to provide an increased capability to engage terrestrial and atmospheric targets with minimum risk and minimum collateral damage. These systems use global view to provide global reach and power without the accompanying increase in physical presence required by terrestrial forces. Similarly, a space-based weapon's ability to attack numerous aim points precisely and in a short time introduces a strong psychological aspect to deterrence and offense. However, space-based weapons have the disadvantages of lift requirements, maintainability, as well as exploitation by the enemy. This section examines issues and proposes creative counter-countermeasures. Concepts considered in this section include

hypervelocity kinetic energy, directed energy, and conventional weapons, as well as unique architectural considerations for effective weapons integration and deployment.

Knowledge is power and it should be fully utilized. In 332 BC, Alexander the Great established Alexandria as the capital of Egypt and its great library symbolized and contained all the knowledge in the civilized world. Over time, invading Romans, Christians, and Muslims controlled, burned, or pillaged the library, waging what might be described today as a form of information war. The fundamental principle of the "Alexandria Concept" is that information is power and that attacking information at its source can help bring its owner to heel. By 2020, the ability to use space to influence someone else's information, both in peace and in war, to further strategic and operational objectives is both realistic and worthy of development. **Projecting Information Power For Peace and War** proposes ways towards the effective use of information to promote stability and enhance the vitality and security interests of the United States and our partners.

The United States ought to strive for superiority in information technology to help maintain its dominant national security posture. Controlling any future enemy's access to and use of the information sphere will comprise a significant portion of the total information warfare concept. Any information warfare capability could be used in a variety of situations, from counter-information acts against recognized adversaries to the continuous benign shaping of the nascent global information sphere. Exploitation of the information sphere through the use of holographic images projected from space in support of unconventional warfare or psychological operations, such as concealment and deception, could add to the future war fighter's "toolbox." This section identifies some projected space-related technologies which could expand a commander's information utilization options, help achieve information superiority or supremacy, and thus improve the security of the nation in the coming decades.

This section also examines a **Counterforce Weather Control** system for force enhancement and identifies the necessary prerequisites for such a system. Atmospheric scientists have pursued terrestrial weather modification in earnest since the 1940s, but have made little progress because of scientific, legal, and social concerns, as well as certain controls at various governmental levels. Using environmental modification techniques to destroy, damage, or injure another state are prohibited. However, space

presents us with a new arena, technology provides new opportunities, and our conception of future capabilities compels a reexamination of this sensitive and potentially risky topic.

This conceptual weather control system is developed through a three-stage predictive analysis process: conceptualize a desired end state, hypothesize the preconditions, and develop measures of effectiveness. The desired end state is limited only by imagination. For example, the capability to "bore a hole" through a cloud to allow unrestricted surveillance of an enemy target may be possible. The difficulty, costs, and risks of developing a weather control system for military applications are extremely high. However, the potential benefits for national security could be even higher. Enemy weather modification weapons are possibilities which, like it or not, may be possible and must be considered.

Recent years have witnessed an expansion of research and discovery of objects from space that potentially may strike the Earth. New and more refined observation techniques shed additional data on the size, nature, and orbit of these objects. These objects vary in size from 10 feet to 6 to 12 miles. It is postulated that 65 million years ago the age of dinosaurs was brought to an end by the impact of an asteroid that measured upwards of 12 miles in diameter. Collisions with objects larger than a few hundred meters in diameter could threaten global civilization and as such the means to mitigate them are worth considering. To have the vision and ability to prepare to defend the planet from natural danger and not do so may be viewed as irresponsible by our own citizens.

Preparing for Planetary Defense: Detection and Interception of Asteroids on Collision Course With Earth develops its theme by initially defining the threat and discussing the surveillance of potential impactors and their orbits. It then examines ways to counter the threat through various mitigation techniques. Finally, it discusses the benefits of a Department of Defense (DoD) role in an international effort and provides some specific recommendations. Although not a traditional "enemy," asteroids are nonetheless a threat that the DoD should evaluate and prepare to defend against. The role of the military has traditionally been to operate in and expand the frontier of space. This role will remain constant as humankind stretches to new frontiers. Provisions for defense of the planet, as far away from the planet as possible, need to begin.

OPERATIONAL ANALYSIS

In this vision of space and the far future, there are constellations of opportunities. The objective of **Operational Analysis** was to provide insight into which of the SPACECAST 2020 system concepts provide the highest leverage and, of these high leverage systems and their embedded technologies, which ought to be pursued first. Since an analytic model for assessing the contribution that different space systems make to the present objective of controlling and exploiting space did not exist, SPACECAST 2020 had to create one. The Air Force Institute of Technology partnered with the operators participating in the SPACECAST 2020 study to build a weighted decision-making aid. The overall goal of operational analysis was to rank SPACECAST systems and their enabling technologies in a way that was traceable and reflected the value SPACECAST participants attributed to them. As "operators" from the line units of the Army, Navy, Air Force, and Marine Corps who were culminating 10 months of intensive thinking about space and the future, the values operators expressed are consistent with what one would expect combatants to value. Even so, each SPACECAST participant is well aware of the complexity of national security decision making in a democracy and in a world of increasingly complex interactions. Thus the model presented is an aid to senior decision makers. Accepting that humans make decisions based on more factors than military utility or operational effectiveness, the rankings presented should be thought of as "raw scores" within the universe of SPACECAST systems. Seasoning the list to change rankings is not only possible, but expected. Public opinion and support, international agreements, and the global political environment should and will influence decision makers as much as considerations of technical risk, cost, and schedule. The definitions and terms used in the draft JCS PUB 3-14, *Joint Doctrine; Tactics, Techniques, and Procedures (TTP) for Space Operations*, provided the baseline for defining the force qualities contributing to the tasks encompassing military space operations.

High-leverage SPACECAST systems and critical supporting technologies clearly emerged from the model. The highest value SPACECAST 2020 systems for development are

- Creation of an integrated demand information architecture to provide the kinds of information demanded by combatants and staffs for Global View.

• Development of a transatmospheric vehicle for space lift and Global Reach.

• Development of a multifunctional space-based laser system for surveillance and counterforce operations for Global Power.

The critical technologies embedded in these systems that must be developed to support assimilation of those systems are

• High performance computing. Exploitation of this technology is currently being led by the private sector.

• Micro-mechanical devices. Because of the utility of systems employing this technology, it is a class of technology being pursued by both the government and the private sector. Opportunities for increased partnership may be high.

• Materials technology is another category of technology useful both to the government and the private sector. It includes classes of metals, ceramics, and carbon and ceramic composites. Although the military's needs for this technology are different in many areas than the needs of industry, it too provides opportunities for partnership in the areas of aviation, space and transportation.

CONCLUSION

The SPACECAST 2020 study produced many new ideas and reinforced some old ones. Its creative and critical approach to future space operations yielded new ideas. These ideas are preserved in appendices which accompany the white papers. Taken together, these offerings are infused with the awareness that by thinking about the future and preparing for it, we are better able to shape the future we desire. *It will take decades to fully exploit some of the ideas offered. By starting now, those decades are available.* Should we fail, for whatever reason, to capitalize on the opportunities the vantage of space allows, it will not be because vision was lacking. To remain a great power in the twenty-first century, our country must choose to do so. This report offers many choices on how this may be done.

SPACECAST 2020, like space itself, has provided the vantage and opportunities to make those choices wisely and well. It is founded on the concept of Global View building on , complementing, and significantly enhancing Global Reach and Global Power. Many of the concepts in the following pages will come to pass. The important

questions are who will acquire these capabilities, how will they be utilized, and for what purpose. The United States is in a position to help shape the outcomes and the nature of the planet in the year 2020 and beyond. The vantage and opportunities offered by space are the means to do so. We seek ***to operate in the transatmosphere and space to promote stability and to enhance the vitality and security interests of the United States and our partners***. The investment, intellectual as well as financial, in the ideas which address the issues confronting the exploitation and control of air and space and the technologies to make them a reality should begin now. SPACECAST 2020 provides the beginning for doing so.

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THE WORLD OF 2020 AND ALTERNATIVE FUTURES

Introduction

One of the initial tasks accomplished by the SPACECAST 2020 participants in the Air War College, Air Command and Staff College, and School of Advanced Airpower Studies was arriving at a consensus on the key features of the far future. Equally plausible, but less likely, alternate futures emerged from the study of the future in a separate and later effort. This section contains four parts describing the five forcing functions molding the future world system; sources of future world conflict; the postulated future interdependency between the military and the civil-commercial sectors; and lastly some plausible alternative futures.

The Future Operating Environment

The objective of studying the potential scope and direction of the changes to occur on the planet in the next three decades was to try to understand the key features of the operating environment of the far future. These features were characterized as "assumptions" about the future. Although the project was called SPACECAST 2020, the study's vision was not restricted to the year 2020. The assumptions and projections made are probably descriptive of the period from about 2010 to 2050.

Many of the features on the future landscape are, or will be, important to space exploitation and control. The assumptions were intended to be useful in defining the boundaries of the national security challenges the US will face. Once the challenges were understood, the capabilities required to respond to them could be described. An understanding of the required capabilities fueled the search for the technologies to satisfy them. An awareness of the need for, and the effects of, some key technologies such as super computing, data fusion, artificial intelligence, directed energy, and inexpensive space lift emerged. Descriptions of the future operating environment did not include potential changes to the roles, missions, or functions of military organizations.

Five Forcing Functions Molding the Future World

Participants believe there are five forcing functions affecting the world system: the number and distribution of people on the planet; the world's geopolitical organizations and interactions; the world's economic processes; the effects of new technologies; and the constraints imposed by the natural environment. Each of these functions will affect US space capabilities in the future.

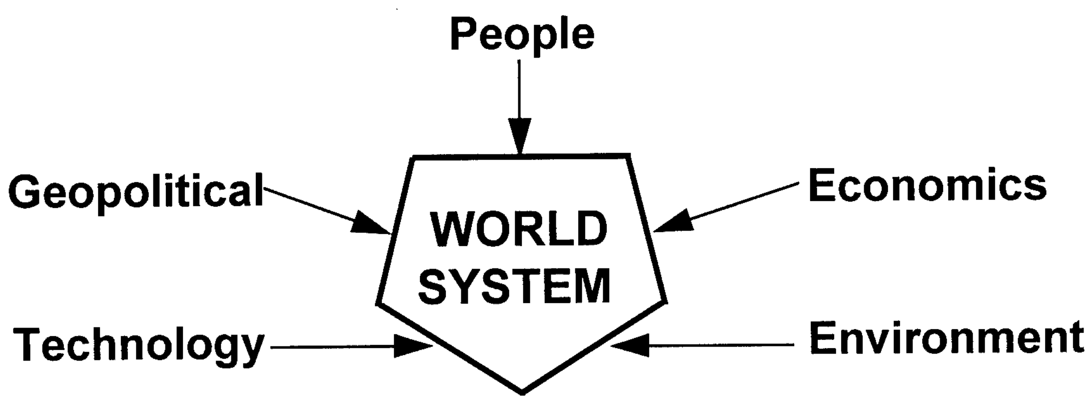

Figure 1. Forcing Functions

These forces are difficult to balance or keep in harmony because many are affected by the decisions of world leaders. In dealing with each other, the SPACECAST study participants concluded human beings have four options: they can cooperate and make the world better together; they can compete with each other, which may or may not make the world better; they can confront each other and negotiate changes to the world system; or they can fight, resulting in conflicts that might hurt or destroy the world system. Whatever the world community decides to do, the ultimate outcome depends on the character of the actors and their modes of interaction.

For the world, these actors are the states and nonstate elements (such as transnational corporations, world organizations, religious movements, or extremist groups). These actors have a military dimension and a civilian dimension, and oftentimes these dimensions are inseparable. For the US and most other post-industrialized states, this area of fusion emerges in responses in four different media: land, sea, air, and space. The SPACECAST 2020 focus was in the medium of fusion called space.

People

Based on available models, the Earth's population is projected to grow from five billion today to over eight billion people by 2020. It will probably double to 10 billion by the year 2035, unless something stops the trend, such as a worldwide plague or another form of catastrophe. The greatest growth is expected to occur in the poorest regions, primarily in the equatorial and Southern Hemisphere countries. Many of the post-industrialized states, most of which are in the Northern Hemisphere, will see a graying of society. This graying will occur due to longer life expectancies in the North made possible by medical and biomedical technology and healthier lifestyles. In contrast, less industrially developed, poorer states (especially in the equatorial regions, in parts of Asia, and in the Southern Hemisphere) will see a young society dominated by teenagers and young adults. This phenomenon will be caused by higher death rates and larger birth rates than in the North. It will be compounded by poverty and the lack of access to education and advanced medical technology.

In post-industrialized states, there will be a significant expansion of the metropolitan/suburban complex. With rapidly expanding telecommunications and information network technology, businesses will not have to be located in the cities to operate. This migration is already occurring in the US today. It will increase significantly in the future. Resulting in regional centers having common concerns (such as transportation, pollution control, and water supply) which can best be handled through regional control. Microstates, similar to Singapore and Hong Kong, may also proliferate.

The labor force, primarily in the wealthy states, will seek and achieve higher levels of individual quality of life. The semi-skilled labor force will want increased leisure time with shortened workweeks and workdays. Its members will want to live in the areas where leisure time can be enjoyed to the fullest and where they can avoid the effects of inner-city crime. Wealthy states will have an increased percentage of the permanently unemployed, probably living as wards of the states. Many of these people will be unable to ride the fast train of a high-technology, computer-oriented society.

Finally, world culture will increasingly be influenced by nonstate associations. Religious extremists of all kinds will exert great influence on human affairs without regard for national borders. Transnational corporations (such as the automotive, fashion, and entertainment industries) will influence the cultural lifestyle. Various environmental

groups will aggressively seek to change government and business behavior and the lifestyle and activities of people. The concept of the state will still dominate the geopolitical arena, even though this arena will be in great flux. New and evolving "states" will result as a consequence of wars of ethnic self-determination, migrations to avoid social discrimination, economic hardship, internal war, resource appropriation or depletion, or the impact of climate variability. The end result of this social and political flux will be more world players, more variables, and more nonlinearity in geopolitical interactions.

Geopolitics

The world will be multipolar, with states loosely organized in regional confederations. The European Community, the Asian Pacific Economic Community, the Organization of Petroleum Exporting Countries, the Organization of American States, and, now, the trading confederation resulting from the passage of the North American Free Trade Agreement are all current examples of this emerging phenomenon. The US will remain a global power far into the twenty-first century because of its wealth, technological superiority, military power, and ability to build consensus among other states. Other great regional centers of power will arise to include Germany--especially if the European Community becomes a strong entity--as well as Japan, China, and perhaps Brazil and Russia.

Nonstate entities will continue to exert great influence. Transnational corporations, criminal and extremist elements, burgeoning private voluntary organizations, and nonstate-based political groups will overtly or covertly seek to play a major role in national and international policy decisions. The role of national governments will become more inwardly focused, concentrating on the welfare needs of their populations and leaving more of the world community concerns to a stronger United Nations or regional associations.

Economics

The world's gross domestic product (GDP) will double by 2020, assuming an average annual growth rate of 3.2 percent for the planet as a whole. The US will remain the world's largest national economy, but its percentage of the world's GDP could be less than the current level of about 22 percent. Trade agreements will become increasingly

more important than state-to-state military alliances and treaties. There will be a strong belief that economic security is more important than military security. Because of the likelihood that transnational corporations will be linking the world's economies, international and national security will become interdependent and almost inseparable. The largest GDP growth is expected in the Asian-Pacific area. The twenty-first century will be the "Century of the Pacific."

Technology

High-speed, high-volume telecommunication technology--coupled with orders-of-magnitude increases in computer speed, storage, and capacity--will make possible the development of vast, interactive computer information data bases that are globally networked. With this technology integration, the vast knowledge of the world could be brought to the individual sitting at his or her own home computer. Adding virtual-reality technology, an individual at home could have the sense of being in another location, interacting visually with other individuals and doing things with them, without ever leaving the comfort of the computer chair. Microminiaturization of computer chips and nanotechnology, coupled with artificial intelligence, will revolutionize product development and greatly expand the use of robotics in daily life.

Information technology and supercomputing will facilitate understanding of the genetic architecture of life forms. By 2020, the world will be engulfed in the beginning of a genetic engineering revolution. This new technology will be used to improve our quality of life and medicine, as well as increase the food supply; however, it will also trigger many moral issues.

There is great promise that economical alternative sources of energy will be developed which will lessen the need for fossil fuels. New sources may come from cold fusion and the new hydrogen technology, as well as vastly improved chemical and solar batteries. Technological research and development could harness energy from the sun by the way of orbiting energy-converter satellites. The satellites could capture the full force of the Sun's radiation, convert it to microwave energy, and transmit the energy via a directed beam to a power distribution point on Earth, where it is reconverted to electricity. Several benefits, including a cleaner environment and a nearly unlimited electric fuel supply, could be realized from this type of technological development.

Technological change will continue to be exponential. With advanced tools; increased creative opportunities; and continuing growth in discovery, storage, and dissemination the rate of change may be more rapid than at any other time in human history.

Environment

The last forcing function shaping the world system is the environment. As the Earth's population grows, the stress on the environment will grow. Past civilizations have undergone forced migrations because of their abuse of the Earth's biomass, primarily from overcultivation and lack of land conservation. With the growth of the population being the highest in poorer countries, there will be significant increases in environmental pollution in these areas. This will further decrease the quality of life of poor states and reduce the available biomass for population consumption.

The average weather for a region will see increasing variability due to human-induced changes in the environment, such as extensive irrigation, overcultivation allowing more dust to enter the atmosphere, increasing carbon dioxide levels in the atmosphere, and increased cloudiness due to air pollution. Some regions may experience extreme climate changes, which could impact the water and the food-producing capability of a region.

The depletion of natural resources will continue to be a concern as the population grows. Most critical will be the availability of fresh, uncontaminated water. A severe drought lasting several years can throw a region into chaos and force the migration of large numbers of people. Wealthy regions will be able to overcome these situations, but poorer regions will have much more difficulty. Contamination of fresh water will continue to increase, especially in the poorer countries. Populations migrating to find food, water, or a more hospitable environment will, in turn, force other environments out of balance.

Future Sources of World Conflict

The future world will not be balanced. The cause of this imbalance will be a significant gap between the "haves" and "have-nots" or “have-lesses” of the world. Large portions of the world will become very high-tech, more materialistic, and somewhat selfish. Wealthy countries will seek increased levels of comfort for their people and will strive for the gain of wealth through the control of knowledge. These countries will make attempts to help the poorer regions, but these attempts will often be ineffective. The populace of wealthy states will resist personal self-sacrifice. People will be very cautious of entering into any venture that may adversely affect their personal well-being. This means they will be more reluctant to support national policies if they believe they will adversely affect their pocketbook and if long-term personal benefits cannot be perceived.

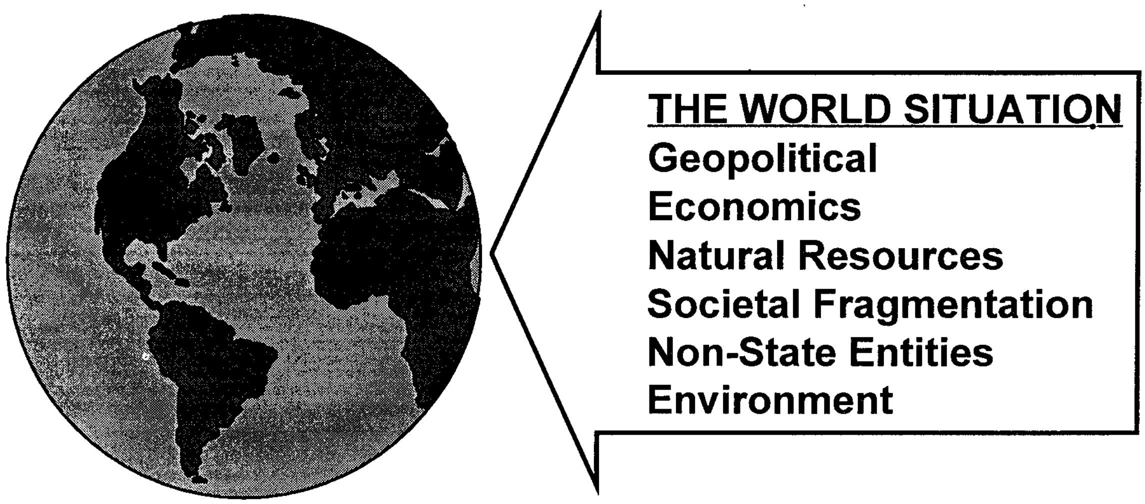

Figure 2. Issues Shaping World's Situation; Potential Sources of Future Conflict

A crisis in values may also occur due to the rise in individualism caused by the immense access to information technology and the pursuit of happiness of the wealthy labor force. Public concerns, such as education, transportation, law enforcement, and medical care, may conflict with the individual's desire to pursue wealth. This force will affect other areas in the future.

In the US the <u>*will*</u> and <u>*character*</u> of the American society will provide strong influence for US space control and exploitation. *Americans will support a more vigorous*

space program only if they see economic benefits coming to them personally and/or if the space program protects the state and their way of life from a perceived threat.

Traditional sources of conflict, such as territorial ambition, regional rivalries, and ancient ethnic or religious hatreds will not go away. Other factors may become even more important in the twenty-first century. The increased prominence of economics in national security could also increase its role as a source of conflict. The belief that economic security underpins and is more important than military security will grow. Rivalry between economic blocs will spark conflicts, some of which may become wars. The gaps between the rich and poor will grow, as will the tension between the groups. Because of these shifts, rich countries are not likely to invest in space unless there is a benefit to economic as well as military security. Space investment for national security will, therefore, need to have commercial applications to be viable. Countries which cannot afford to invest in space for either commercial or national security purposes may be among the "have-not" countries of the twenty-first century.

Resource limits may lead to competition and perhaps conflict. Those who "have-not" or "have-less" may come into conflict with those who "have." Resource management leveraging monitoring from space could help to alleviate some of these resource problems. The fragmentation of societies and the differences between racial, ethnic, religious, political, or special-interest groups will cause conflicts within states and between states. New states will arise out of wars of ethnic self-determination. Today's "family" of 170 to 180 states will increase to perhaps as many as 250, with most new states forming along clan, tribal, or ethnic lines in the regions of Eastern Europe and Africa. This proliferation of states and groups on earth will present an additional monitoring problem for the US. More space systems will be required to be aware of and perhaps influence world events.

In the twenty-first century, states will not become irrelevant or obsolete. However, the number, influence, and power of nonstate actors will continue to increase. The number and power of criminal, ethnic, and religious groups will also increase. Extremist factions will continue to exist. Air, sea, and land piracy, smuggling, trafficking in outlawed goods, blackmail, theft of information, industrial espionage, technology sabotage, and other activities will bring states into conflict with nonstate groups. Armed force, violence, and terrorism used by nonstate groups will continue to pose a threat to states. Weapons of mass destruction and the means to deliver them will proliferate. The

global situational awareness provided by space forces can help with understanding the movement and activities of these hostile state and nonstate groups. Above and beyond the inherent advantages of monitoring the activities of single states, global situational awareness can help us stay ahead of nonstate groups by identifying linkages between the separate terrorist or other "cells" scattered around the world.

Environmental noncompliance, including violation of nuclear and hazardous waste disposal agreements and the violation of water rights, will be sources of conflict. Sensitivity to environmental threats will make world powers willing to use coercive means up to and including force to bring environmental dangers under control. The sovereignty of states in the future will include their perceived right to clean air and water. Multispectral systems will be essential for global monitoring of the environment. States will use space systems to fix blame and liability on violators.

Future Interdependence between the Military and Civil/Commercial Sectors

There is an area of fusion or overlap between the range of civilian and military responses to the new world, specifically in the medium of space. States with affordable and as-required access to space will have commercial and military advantages over those who do not. The great powers will remain great in the next century only if they have assured access to space.

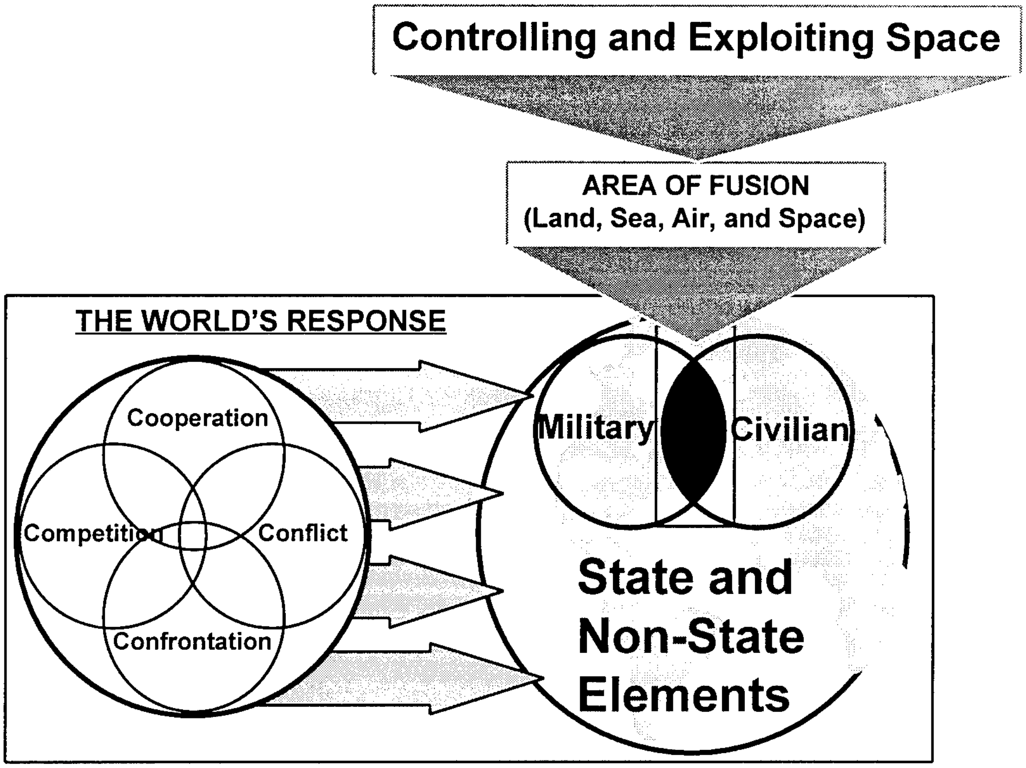

Figure 3. Controlling and Exploiting Space

The world will see orders of magnitude improvements in many areas. Lightweight materials and improved propulsion technology will give the US and other states affordable access to space. Artificial intelligence systems, supported by supercomputers, will use fused information derived from space systems to automatically generate threat forecasts, courses of action, and best responses for consideration by human decision makers. Onboard supercomputers, improved sensors, and satellite proliferation caused by reduced lift costs will make space systems less dependent on ground infrastructures for tracking, telemetry, and satellite control. Directed-energy weapons can permanently or temporarily disable satellite functions and will probably be the preferred antisatellite weapons technology for wealthy states.

As the US proceeds into the next century, resource constraints may cause civil, commercial, and military space activities to converge with increasing military use of civil/commercial space applications. Distinctions between military and commercial space systems will continue to erode. An increased number of military systems will be military only because of the ways in which the military manipulates, fuses, and uses the data provided by commercial systems. The military will cooperate with and rely on the private sector to provide more or most of its space capability for computing,

communications, navigation, weather, and Earth resources sensing. Many scientific activities will also be useful for commercial and military purposes. Exploiting these synergies could help develop technologies and operational concepts for national security applications. Civil remote sensing for national security purposes will continue.

Resource limitations may provide opportunities for cooperation between the Department of Defense and nonmilitary space organizations. On the commercial side, these activities or industries will benefit from the same advances in compact supercomputers, affordable lift, improved sensors, and directed-energy data transmission, as will the military. If economic security is seen to underpin military security, the success of these activities or industries will be necessary to guarantee America's place as a world power in the next century.

Affordable, as-required spacelift could provide the US as much surveillance; navigation; and command, control, and communications capabilities as it requires. It could also provide space systems that give the decision makers instantaneous awareness and virtual presence anywhere on the planet. Affordable lift could also give combatant forces small, commander-launched and controlled combat space systems for information warfare, electronic combat, precision weapon guidance, target identification and illumination, and up- and down-linking with unmanned aerial vehicles. Wealthy countries will consider their space infrastructure part of their sovereign territory and will develop robust antisatellite and advanced satellite defense technologies to protect it. Superiority in speed, position, and information will be the keys to dominance in combat environments. Much of this technology will be proliferated, however, and many states will have a deployed or breakout antisatellite capability.

Because of national dependence on space-derived information, space surveillance and control will become as important as airspace or sea-lane surveillance and control. An international body could assume more responsibility for space surveillance and satellite deconfliction operations. Coalitions of the great states may also operate space-based equivalents of the airborne warning and control or joint surveillance target attack radar systems to allow continuous observation of the Earth's surface to detect and deter hostile military activities.

There are other specific areas in which international cooperation in space could occur. With more and more states entering into the space arena, the need for

deconfliction of orbits will increase. Orbital space debris is an increasing hazard to our activities in space. Debris in orbit, some of which is too small to be tracked by Air Force Space Command, presents a potentially lethal threat to space operations and has made some desirable orbits unusable. States need to seek a way to cooperatively control and collect space debris. Also hundreds, perhaps thousands, of asteroids travel in orbits that intersect the Earth's orbit. Some have struck the earth in the past and left large craters. Others have come very close. Action should be taken to increase the world's capability to detect and define the orbit of the asteroids as well as to deflect or destroy those asteroids predicted to impact earth.

With the expected proliferation of nuclear weapons and delivery systems, there would be a need to deploy defensive systems capable of protecting important areas of operations by detecting theater, national, and international missile launches. States or nonstate elements could subscribe to the protection service. If economic interdependence is an expected characteristic of the future, cost-sharing partnerships should also be expected.

Alternative Futures

The discussion above was an outline of the future, as the SPACECAST 2020 participants saw it. In the process of brainstorming and consensus building, the participants identified a creative and fertile "rogue set." During the preparation period of the study, members were exposed to diverse speakers, who shared visions of a large number of alternative futures. It was important to develop and assess SPACECAST 2020 concepts and technologies within the context of alternate future worlds to highlight high-leverage ideas and to debunk risks. SPACECAST 2020 did that with a group of eight individuals from the SPACECAST 2020 team, led by Colonel Jae Englebrecht of the Air War College and supplemented by external assistance from the Futures Group. The Futures Group is an international strategy and consulting firm assisting in strategic planning and scenario development for corporations. Together this SPACECAST Alternative Futures Group developed scenarios, alternate futures or alternate worlds, terms used relatively interchangeably. Scenarios, intended for use as background for planning and assessing alternate strategic courses of action, are descriptions of future conditions. They describe a plausible evolution of important events and trends and

present a range of possibilities central to an organization and its mission. Scenarios are not forecasts of what will be. They are ways to capture the breadth or range of future challenges and opportunities.

To build scenarios leading up to alternate futures, the group considered which "drivers" of strategic planning interest to the US would dominate the world. The group considered over 60 potential drivers, some of which included: political and economic actors in power centers; organizing principles of actors; the future vulnerability of data, hardware and transmission; terrorist disruption and disruptive potential; the degrees of cultural commonality and continuity that could be envisioned in the world; technology diffusion and proliferation; US competitive capability; interest groups and constituents; population growth in developing countries; the nature and extent of military alliances; political instability in the third world; centralized or decentralized power distribution; the relative economic strength of the US; the availability of energy and natural resources; the size of the US defense budget; the degree of regionalism; the degree of global economic integration; the degree of conflict; global economic capability; political and social will as it relates to space; biogenetic threats or havens; insufficient incentives to be involved in space; public infatuation with space; the locale in which military activities will take place; the type of weaponry available; and, world economic conditions. These drivers were later grouped by affinity as the planner brainstormed to decide what were appropriate factors to consider for the alternative futures scenarios. Three dimensions emerged: the number of actors playing a role in space; the will of the actors to use space; and the technological and economic vitality of the actors, or their "technomic" capability. Varying these dimensions to their extreme (few to many, weak to strong, low to high) yielded eight alternate futures.

The SPACECAST Alternative Futures Group identified these different worlds and named them. The group decided there were four alternative futures most relevant for planning purposes. These were a Spacefaring world, a Rogue's world, Mad Max Incorporated world, and a Space Baron's world. These were worlds in which more space activity or more desire to be involved in space were deemed most relevant or interesting for planning purposes.

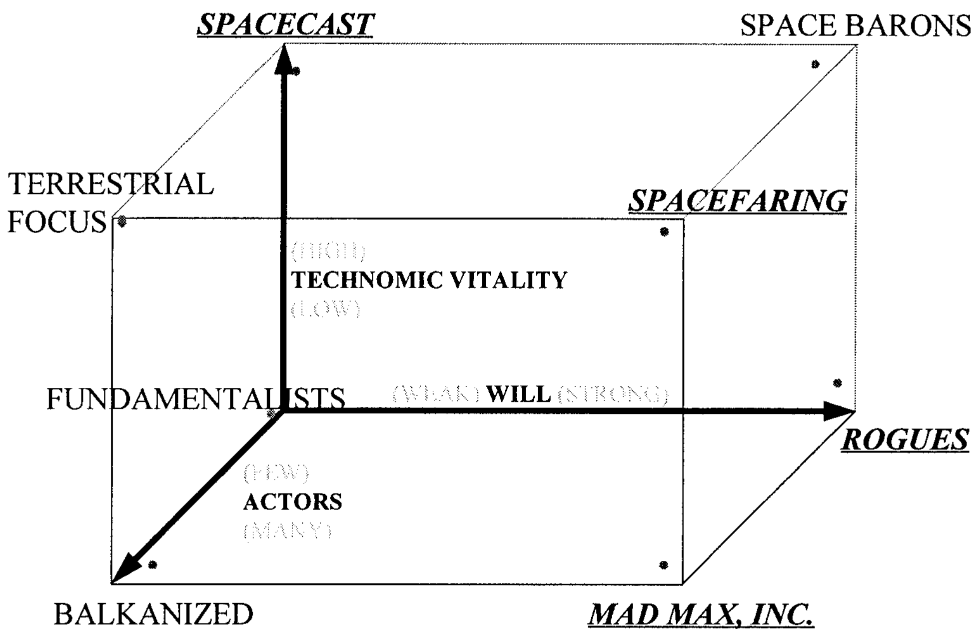

Figure 4. Alternate Worlds of 2020

The group noted that the Space Baron's world was very close to the SPACECAST 2020's most likely future. Scenarios were built for each of the worlds. These were internally consistent and included a plausible history logically connecting the future world with the present one. An examination of the four worlds allows awareness of the key features of many plausible future operating environments.

Spacefaring World

The first world is a Spacefaring world, a world in which there are many actors with a strong desire to be involved in space and with high technomic vitality representing the capability to be involved in space. Prior to 2020, there will be advances in communication and information interconnectivity and success of the Global Agreement on Trade and Tariffs (GATT), leading to a highly interdependent global village. The few remaining rogue states that may have inhibited development and spread of space and technological activity will have been swept away by dual waves of *glasnost* and economic activities. The competitive atmosphere among states and transnationals had leading to the early development of advanced space-launched methods, and cheap, reliable spacelift have become available from a variety of sources, which might include states and corporate barons. This fierce competition extends into the economic realm and

into space, but it has developed in a fairly friendly and non-conflictual manner. As these events unfold, the military increasingly assumes the role of policeman and space-traffic controller. The entertainment and education industries respond to these developments by increasingly using space as a setting for both entertainment and education, continually sparking the imaginations of populations worldwide.

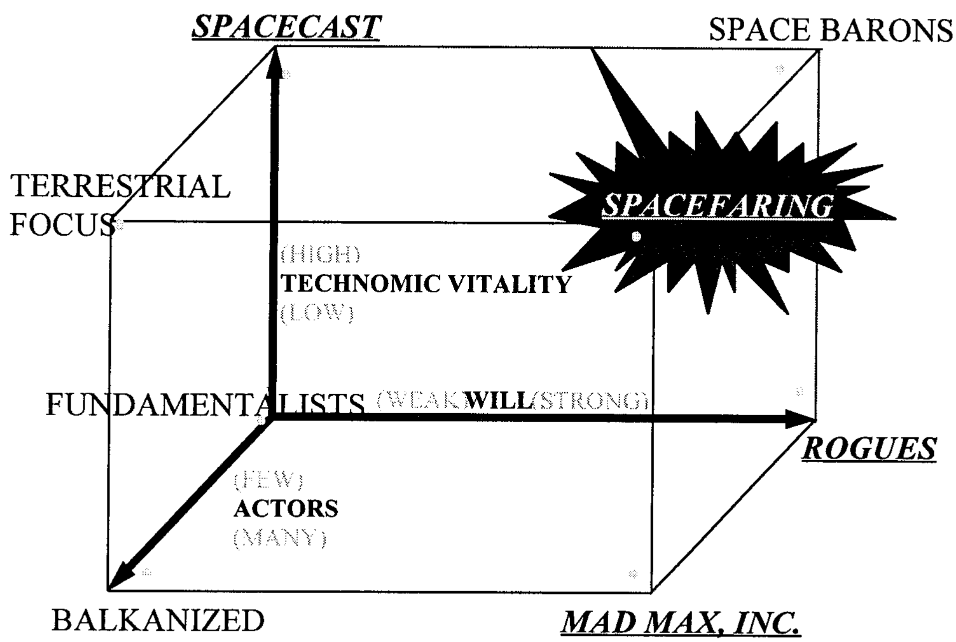

Figure 5. Spacefaring World

The features of this Spacefaring world are characterized by their dimensions; that is, many actor's, technomic vitality, and strong will all result in high involvement in space. Specifically, the government is one of many actors in the Spacefaring world where individuals, transnationals, and supernationals are all highly active and competitive within a stable interdependent environment. A Spacefaring world is characterized by free trade and a global industrial policy. Space investment is an economic reality with wide economic opportunity available to many. Global technology proliferation is a character and feature of this world, with space surveillance, communication, and cellular information nets proliferating. Energy is cheap and prolific, and advanced propulsion systems are available. Education is global. Cheap information technology is available for many. A strong will and desire to be in space is characterized and motivated by great economic opportunity and growth. Actors are interested in some cooperation in planetary

defense. High imagination is another feature encouraging involvement. Space visionaries and entertainers and space tourism are standard features of this world. Political leadership encourages such growth, and its encouragement is evidenced by an adherence to space law and strong space constituent groups to encourage continued activity. The decentralized structures in this world are supplemented with sophisticated social service and social support services.

A Spacefaring world has unusual implications for the nature of space activity and the nature of the military role in space. In this world, space activity is proliferated, global, and expanding and the military is involved across the board, even though the militarization of space is limited. Counterforce activity is rated low when compared to other worlds. Many military activities are related to deconfliction and potential planetary defense. Logistics activities carried out by the military is rated low, in large part because this function is performed by other enterprises. Monitoring or reporting has a moderate requirement for the military use, but much of this activity is dual-use and will be expanding in both military and civilian sectors. The civilian and government role in space is very high, while the level of commercial involvement will be rated very high. Commercial lift is abundant and available and cost per pound for lift is cheap. Humans are common in space in this world. In fact, there are discussions and initial activity toward hotels and space stations in space. While the Spacefaring world has interesting implications for the US and the US military in space in the world of 2020 and provides a useful background for planning purposes, other alternate futures would present highly different and unique challenges.

Rogue's World

The second alternate future developed was called the Rogue's world. This is a world in which there were few actors with a desire to be in space and limited technological and economic capability, but the will of some actors to be involved in space will be very high. The history leading up to this world might be a failure of GATT, spawning an era of neoprotectionism and a world economic downturn. Advances in communication and information interconnectivity failing to overcome deep-seated prejudice and traditional cultural barriers. Fundamentalist and extremist Islamic states becoming closed, highly controlled societies in a quest for cultural purity. More than one Rogue state developing reliable indigenous spacelift, a demonstrated antisatellite

capability, and a willingness to violate space law. This perceived threat brings renewed US emphasis on space defense and an increased military role in space.

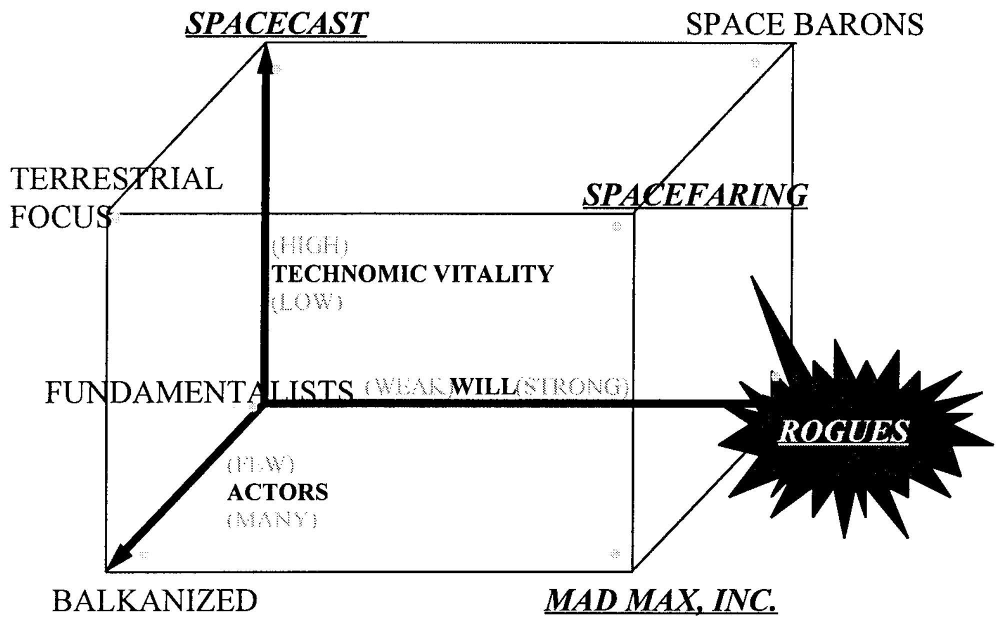

Figure 6. Rogue State(s) World

The features of this world are characterized by its dimensions: a few actors, low technomic vitality, and a strong will for involvement by some. The actors in this world are principally states and political actors. For example, some might have a totalitarian or a highly ideological state, and these Rogues will be seeking influence. There will be few entrepreneurs in this world, and it will be characterized by shifting alliances. The low technomic vitality will be characterized by tiered shifting economies, protectionism, and embargoes against the Rogues. These Rogues will be willing to sacrifice domestic needs to preserve national security and to receive the prestige associated with space activity. The technologies they will rely on will essentially be indigenous technology, and this world will have limited or little advanced propulsion. The propulsion and lift existing will be mainly military. Information in this world will be expensive and dispersed. Fiber optics will be controlled by the state as it attempts to control information to its population. Its population will be educated in an irregular fashion. The state might be motivated by a threat from some ideological or religious adversaries. These adversaries might have weapons of mass destruction in space. The perceived high value associated with space resources will provide strong incentives to protect space assets against a

perceived threats. Political leadership will be key both in causing the Rogue state to take its position as well as to produce a response from the US. The nature of space in the Rogue's world will essentially be limited, but it will be perceived to be critical. The military's role in space will be on the rise. Counterforce potential will be very high, particularly with the development of ASAT. The military's logistics role in space will be moderate. Its role in monitoring and reporting will be high. The relationship between civilian and government activity will be weak and the amount of activity will essentially be low. The level of commercial activity is rated low. The cost per pound of lift will be slightly more expensive than is envisioned today. Spacelift will be government dominated. There will be no or limited human activity in space.

Mad Max Incorporated World

The Mad Max Incorporated world is a world characterized by many actors with a strong desire to be in space, but actors who are limited by very low technomic vitality. This world is very conflictual. The Mad Max Incorporated world history is characterized by a small nuclear exchange (not involving the US) and a resultant environmental nightmare occurring in South Asia. A devastating earthquake in California decimates the US economy and leads to mass internal migration. Post industrial states increasingly shift to social programs, environmental cleanup, disaster relief, and a complex internal regulatory environment. Multinational corporations, are quicker to recover than states, fill the void by privatizing many other former public sector tasks. Corporate and individual economic concerns lead to decreased clout for states and a further rise of multinational corporations. Many military forces, including space assets, were increasingly made available to the highest bidder in order to sustain their activities.

Space actors in this world are essentially corporations. Governments in the Mad Max World have become welfare states or welfare guardians. The highly regulatory environment with complex political and legal interconnectivity forces corporations to transcend the geographical constraints of government. The low technomic vitality is characterized by the continuous shifting of internal corporate resource allocations as companies move money from state to state to meet their needs. Trade is moderate, and corporations are pursuing profits while states are focused on domestic needs.

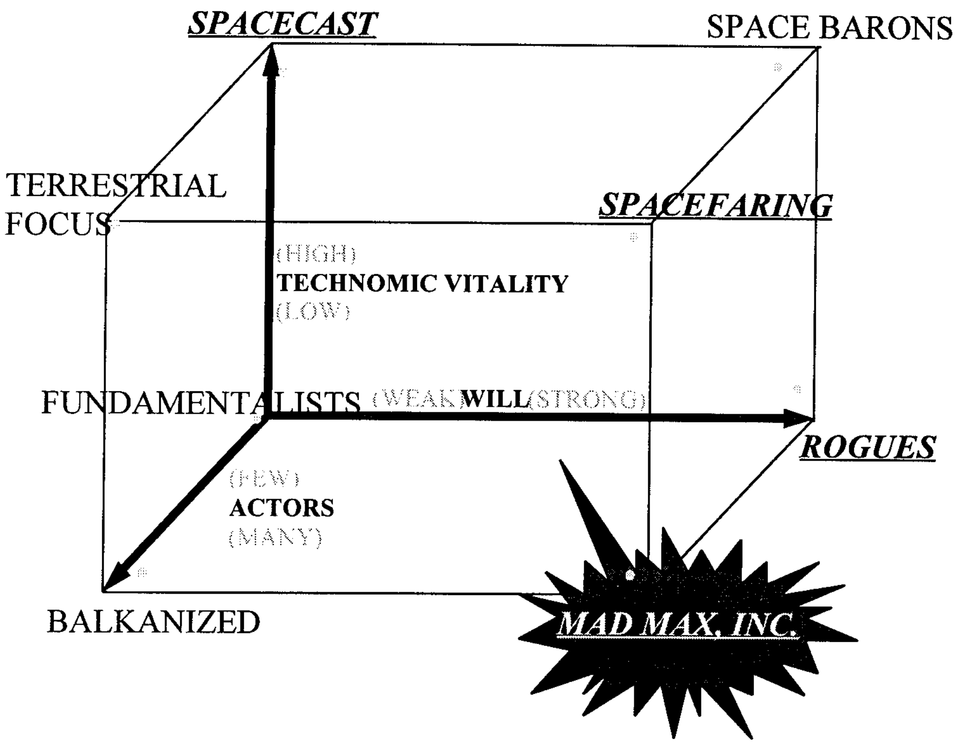

Figure 7. Mad Max, Inc. World

Technology and proliferation are irregular. There is limited advance propulsion, but some corporate lift. Information is irregular. States provide basic information, but sophisticated information nets abound. Information security is a prime value for corporate economic purposes. Education is provided by the state in its basic form, but corporate educational and training, or feudal universities, are developing in the Mad Max world. These actors are motivated to provide a corporate haven from the regulations in space. Resource and energy opportunities in space are driving the actors' activity. While wide-scale political and social space vision has been lost and corporations are seeking a niche in space, political leadership is being domestically focused on the tasks of welfare and protection of the environment.

The nature of space in the Mad Max world takes a commercial focus with military activity decreasing. Counterforce activity is very low and, to the extent that it exists, is chiefly corporate. Military logistics is very low and is commercially driven. Monitoring and reporting is moderate with dual uses, between government and military on the one hand and corporate business on the other. Civilian government roles are low to moderate. There is low civilian government activity versus high commercial activity. The cost per

pound for lift is lower than it is today and is essentially commercial. The potential for humans in space is moderate in the Mad Max world.

Space Baron's World

The fourth alternative future developed was called the Space Baron's world. Space Barons are individual entrepreneurs involved in space. According to the plausible history leading to the Space Baron's world a single nuclear incident occurs prior to 2020, but states avoided World War III. States continually shift from military to economic competition. Increasingly, wealthy northern countries form several pragmatic alliances and consortia widening the gulf between "have" and "have-nots." High-tech alternate terrestrial options such as fiber optics slow the drive to develop advanced space systems. The lack of political will to be in space opens the window to Space Barons such as Motorola, Microsoft, and CNN (Cable News Network).

The features of the Space Baron's world are represented by few actors, high technomic vitality, and moderate to low will to get involved in space. The players are states and corporate space barons. The US will dominate such a world but will not have a monopoly. The technomic vitality is represented by regional and transnational economic blocks. Space money will be subject to budget cuts, and military/civilian dual-use activities and projects will be important for conserving limited financial resources.

Technologies will be moderately proliferated, some advanced propulsion technology will exist, and information will be characterized by increasing local area networks. Education will increasingly integrate computers to assist in tasks. Will and involvement will be characterized by few states concerned about security threats, and a few space barons seeking economic niches and profits. Imagination will not evoke space images or encourage space exploration. Political leadership will be divided between an earth and a space focus. The social structure will essentially be democratic and multipolar.

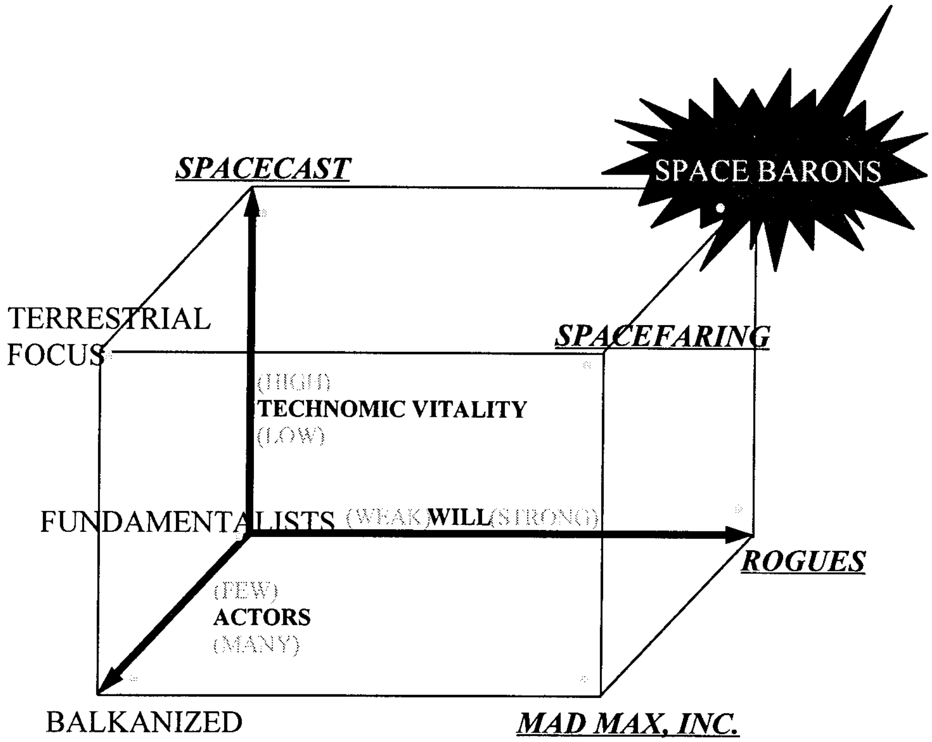

Figure 8. Space Barons

Military activity will support space logistics, counterforce, and monitoring and reporting from space, but all will be limited. Counterforce activity force will be limited. Logistics activity will be very limited, except for the space barons. Monitoring and reporting will be chiefly a military task. The level of civil government activity will be low. The level of commercial activity will be moderate. In terms of lift, the cost per pound will be slightly cheaper than today but no breakthrough in lift technology will be envisioned producing a need for cooperation between civil and military sectors. The potential for humans envisioned in our most likely future is low.

It is important to note the differences between the SPACECAST 2020 world and the Space Baron's world. Each world will lead to different space architecture's. If Space Barons dominate space development, research and development will produce systems designed without concern about hostile conditions and high vulnerability to attack. In addition, in a Space Baron's developed world, potentially there will be degraded US intelligence and communications caused by reduced abilities to collect against noncooperative targets. The principle difference between the most likely SPACECAST

2020 future and a space world dominated by Space Barons will be who owns the space architecture.

Conclusion

SPACECAST 2020 teams used the different proposed futures to enrich their concepts, even though the SPACECAST 2020 concepts were not constrained by the above assumptions. The intention was to describe what the participants believe it will take for America to continue to control and exploit space. Thus, each of the future space world scenarios served as a vehicle for testing the concepts and capabilities having emerged from the SPACECAST 2020 studies. In this way, neither the technologies nor the social, economic, political, or military constraints and opportunities were developed in isolation. The constructs emerging were therefore more robust and viable than they otherwise would have been. The papers that follow, including the "Operational Analysis," used these futures to help develop and appreciate capabilities and to assess their utility across a range of plausible futures. By looking far ahead, SPACECAST participants have come to appreciate that we need not resign ourselves to being victims of the future. We can help slope the future we desire. The papers that follow describe creative ways by which we can slope the future.

GLOBALVIEW: AN INFORMATION DEMAND SYSTEM FOR THE JOINT WARFIGHTER OF TOMARROW

This paper is included in Volume IV

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LEVERAGING THE INFOSPHERE

SURVEILLANCE AND RECONNAISSANCE IN 2020

Tomorrow's Challenge Today

Warfighting and conflict management into the 21st century will require improved concepts and applications of technology in the areas of surveillance and reconnaissance. As defined by the JCS, surveillance is the "systematic observation of aerospace, surface, or subsurface areas, places, persons or things by visual, electronic, photographic or other means."[1] Similarly, reconnaissance refers to "a mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or potential enemy."[2] Both surveillance and reconnaissance are critical to US security objectives of maintaining national and regional stability, and preventing unwanted aggression around the world. As the US moves into the 21st century in a world of diverse dangers and threats marked by the proliferation of weapons of mass destruction, unconventional warfare, and sophisticated enemy countermeasures, surveillance and reconnaissance are not only critical, but essential for achieving the "high ground" in information dominance, conflict management and warfighting.

Key to achieving information dominance will be the gradual evolution of technology, i.e., sensor development, computation power, and miniaturization, to provide a continuous, real-time picture of the battle space to warfighters and commanders at all levels. Advances in surveillance and reconnaissance, particularly real-time "sensor to shooter" to support "one shot, one kill" technology, will be a necessity if future conflicts are to be supported by a society conditioned to "quick wars" with high operational tempos, minimal casualties, and low collateral damage.

To meet the rigorous information demands of the warfighter, commander and National Command Authority (NCA) in 2020, a system and architecture must exist to provide a high resolution "picture" of objects in space, in the air, on the surface, and below the surface--be they concealed, mobile or stationary, animate or inanimate. The true challenge is not only to collect information on objects with much greater fidelity than is possible today, but also to process the information orders of magnitude faster and disseminate it instantly in the desired format.

The Concept

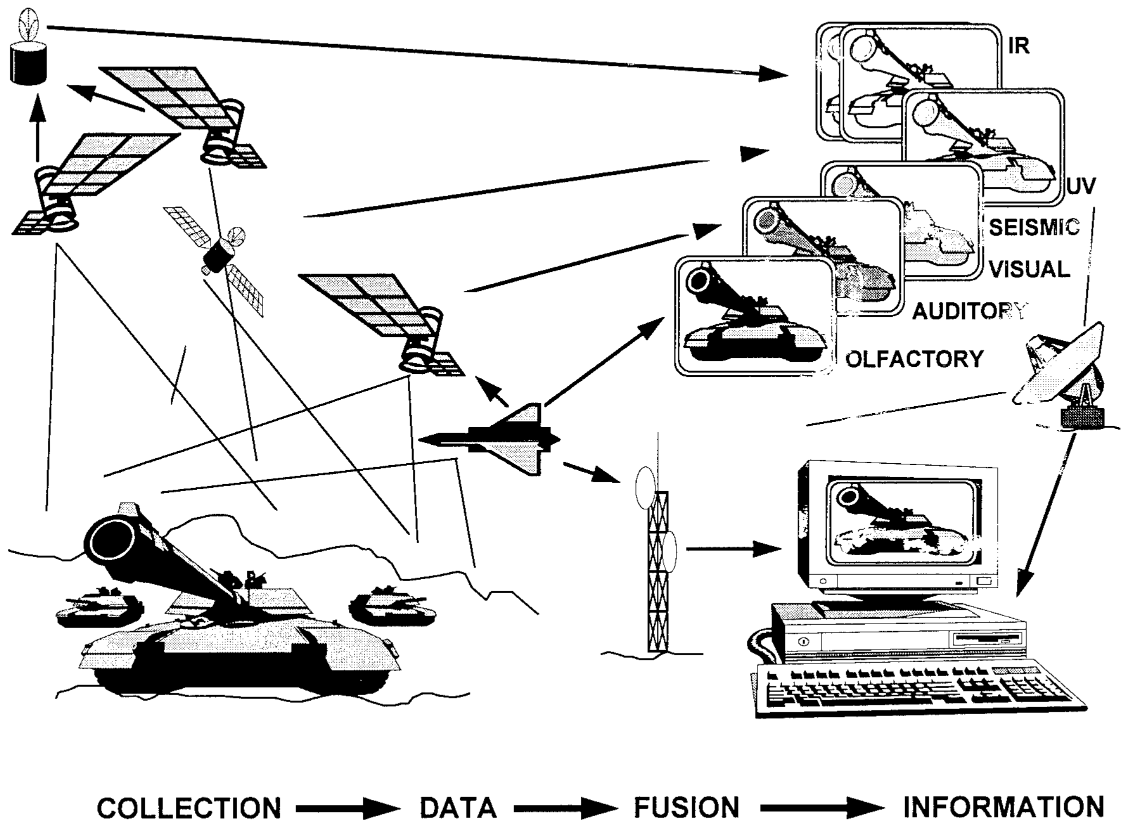

Figure 1. The Concept

The Key to the Concept: Structural Sensory Signatures

The critical concept of this paper is to develop an "omni-sensorial" capability that includes **all** forms of inputs from the sensory continuum (See Figure 1). This new term seeks to expand our present exploration of the electromagnetic spectrum to encompass the "exotic" sensing technologies proposed in this paper. This system will collect and fuse data from all sensory inputs--optical, olfactory, gustatory, infrared, multispectral, tactile, acoustical, laser radar, millimeter wave radar, x-ray, DNA patterns, HUMINT, etc. to identify objects (buildings, airborne aircraft, people etc.) by comparing their *structural sensory signatures (SSSs)* against a pre-loaded data base in order to identify matches or changes in the structure for identification or comparison. The identification aspect has

obvious military advantages in the indications and warning, target identification and classification, and combat assessment processes.

An example of how this technique might actually develop involves establishing a *sensory baseline* for certain specific objects and structures. Using a known source, such as an aircraft or building full of nuclear or C4I equipment, the system would then optically scan from all angles; smell; listen to; feel; measure density, infrared emissions, light emissions, heat emissions, sound emissions, propulsion emissions, air displacement patterns in the atmosphere, etc.; and synthesize that information into a *sensory signature* of that structure. This map would then be compared against *sensory signature patterns* of target subjects such as Scud launchers or even individual people. A simple, but effective example of a *sensory signature* was discovered by the Soviets during the height of the cold war. They discovered that the neutrons given off by nuclear warheads in our weapons storage areas interacted with the sodium arc lights surrounding the area, creating a detectable effect. This simple discovery allowed them to determine whether a storage area contained a nuclear warhead.[3]

Sensory identification could then use the information to create virtual images (similar to the way architects and aircraft designers use three dimensional computer aided design (CAD) software), including the most likely internal workings of the target building, aircraft or person so one could actually "look" inside and see the inner-workings. A good example of this is Boeing's use of CATIA (Computer Aided Three Dimensional Interactive Application) for design of their new 777 aircraft. The "virtual airplane" was the first aircraft built completely in cyberspace--to be built entirely on the computer so that it could be "looked at" throughout before being built physically

This "imaging" could be carried one step further by techniques such as non-invasive magnetic source imaging and magnetic resonance imaging (MRI), which are now used in neurosurgical applications for creating an image of the actual internal construction of the subject.[5] In fact, the numerous non-intrusive medical procedures now used on the human body might be extrapolated to extend to "long-range" sensing. Procedures similar to MRI and the use of nuclear medicine to look inside the body for anomalies could be used on targets at a distance. The nuclear materials for these "structural MRIs" could be delivered by PGMs or drones and introduced into the ventilation system of a target building. The material would circulate throughout the

structure and eventually be "sensed" remotely to display the internal workings of the structure.

Another extension of the concept of distance sensing would be the tracking of mitochondrial DNA found in human bones. DNA technology is currently being used by the US Army's Central Identification Laboratory for identifying war remains.[6] If this technique could be used at a distance, tracking individual human beings is conceivable. When extrapolating these techniques from medicine, the possibilities are endless. Detection of vapors and effluent liquids associated with many manufacturing processes could be accomplished by a mass spectrometer that ionizes samples at ambient pressure using an efficient corona discharge.[7] These techniques are currently found in state of the art environmental monitoring systems. There are also spectrometers that can analyze chemical samples through glass vials.[8] Applying this technology from a distance and collating all the data will be the follow-on third and fourth order applications of this concept.

Another technology that would aid the identification of airborne subjects would be NASA's new Airborne In Situ Wind Shear Detection Algorithm.[9] Although designed to detect turbulence, wind shear and micro burst conditions, this technology could be extrapolated to detect aircraft flights through a given area (maybe using some sort of *detection net* for national or point defense). This, coupled with disturbances in the earth's magnetic field, vortex detection tracking of CO_2 vapor trails, and identifying vibration and noise signatures would create a *sensory signature* that could be compared against a data base for classification (See Figure 2).

The overall system would accumulate sensing data from a variety of sources such as drone or cruise missile delivered sensor darts embedded in the structures, structural listening devices, space based multispectral sensing, weather balloons, probes, airborne sound buoys, unmanned aerial vehicles (UAVs), platforms such as AWACS and JSTARS, land radar, ground sensors, ships, submarines, surface and subsurface sound surveillance systems, human sources, chemical and biological information, etc. The variety of sensing sources would serve several functions. First, with many sources of information coming in on a particular target, spurious inputs could be "kicked out" of the system, or given a lesser reliability value, much like the comparison of data from an aircraft equipped with a triple Inertial Navigation System when there is a discrepancy among separate inputs. Another important factor in handling a variety of inputs is that it makes the system increasingly harder to defeat when it does not rely on a few key inputs.

Finally, inputs from other nations and the commercial sector may be used as additional elements of data. Just as the current Civil Reserve Air Fleet (CRAF) system requires certain modifications for commercial aircraft to be used for military purposes in times of national emergency, commercial satellites might contain subsystems designed to support the system envisioned above. In such a redundant system, if some data was not received, it would not have debilitating impact on the system as a whole.

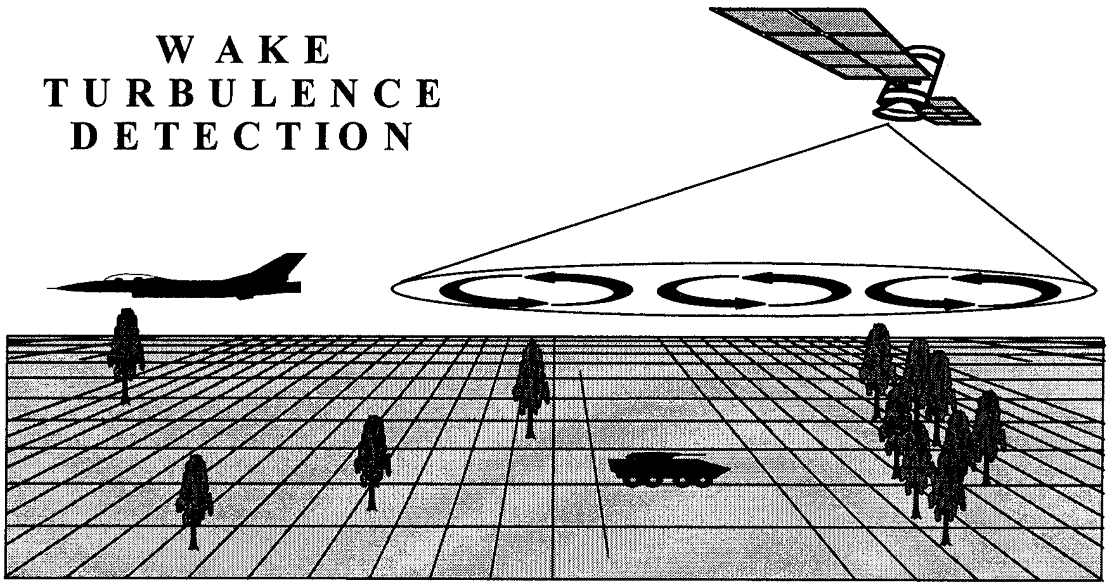

Figure 2. Wake Turbulence Detection

To fuse and compare the data, the processors could take advantage of common neural training regimens and pattern recognition tools to sort data received from each of the sensor platforms. Some of the data fusion techniques we envision would require continued advancement in the world of data processing. Data processing capability is growing rapidly, as noted by Dr. Gregory H. Canavan, Chief of Future Technology at Los Alamos National Laboratory:

> Frequent overflights by numerous satellites adds the possibility of integrating the results of many observations to aid detection. That is computationally prohibitive today, requiring about 100 billion operations per second, which is a factor 10,000 greater than the compute rate of the Brilliant Pebble and about a factor of 1,000 greater than that of current computers. However, for the last three decades, computer speeds have doubled about every two years. At that rate, a factor of 1,000 increase in

> rate would only take about 20 years, so that a capability to detect and track trucks, tanks, and planes from space could become available as early as 2015.[10]

Dr. Canavan also suggested that development time could be reduced even further by using techniques such as parallel computing and using external inputs to reduce required computation rates. The point is that with conservatively forecast advancements in computer technology the ability to gather and synthesize vast amounts of data will permit significant enhancements in remote sensing and data fusion.

Using Space

As envisioned, this concept would be supported by systems in all operational media--sea, ground, subterranean, air and space. However, space will play the critical role in this conceptual architecture. Although the system would rely on data from many sources other than space, there are some definite advantages in using space as a primary source of data for sensing and fusing. Space allows prompt wide-area coverage without the constraints imposed by terrain, weather, or political boundaries. It can provide worldwide or localized support to military operations by providing timely information for such functions as target development, mission planning, combat assessment, search and rescue (SAR), and special forces operations.

Sensing, Fusion and Dissemination

The overall concept can be divided into three parts: The *sensing phase* using the ground, sea, air, and space based sensors; the *data fusion phase* which takes the raw data and produces information; and the *dissemination phase* which delivers the information to the user. The dissemination portion is discussed in the SPACECAST 2020 white paper entitled, "Global View."

Sensing

In approaching the whole concept of sensing, this paper uses the five human senses as a metaphor. Although this is not a precise representation, it at least provides a convenient beginning point for our investigation. For instance, in the living world, human sensing capabilities are often inferior to the sensing capabilities of other forms of

life, e.g., the dog's sense of smell or the eagle's formidable eyesight. This concept revolves around exploring the technological limits of sensing.

There have been tremendous strides made in the sensing arena. However, some areas are more fully developed than others. There have, for example, been more advances in the optical or visual than in the olfactory (smell) ones. This paper not only examines the more traditional areas of reconnaissance such as multi-spectral technology, but discusses interesting developments in some rather unique areas. An exciting element of this paper is the discovery of research being conducted in the commercial realm where very specific technologies for specific tasks are needed, and where these techniques may not have as yet been fully investigated for military uses.

The sensing areas examined here are: "visual" (to include all forms of imaging such as infrared, radar, hyperspectral, etc.), acoustic, olfactory (smell), gustatory (taste) and finally tactile (touch). There are two keys to this metaphoric approach to sensing. First, it unbinds the traditional electromagnetic spectrum orientation to sensing. Second, it provides a way of showing how all these sensors will be fused to allow fast, accurate decision making such as that provided by the human brain.

Visual Sensing and Beyond

As mentioned above, remote image sensing received a tremendous amount of attention both in military and civilian communities. The intention of this paper is not to reproduce the vast amount of information on this subject, but to briefly describe the current state-of-the-art and highlight some of the more innovative concepts from which we can step forward into the future. We will not discuss US national imaging capabilities other than to emphasize they will need to be replaced or upgraded to meet the needs of the nation in 2020. The technologies and applications discussed below pave the way for these improvements.

Multispectral Imaging

Multispectral imaging (MSI) provides spatial and spectral information. MSI is currently the most widely used method of imaging spectrometry. The US-developed LANDSAT, the French SPOT, and Russian *Almaz* are all examples of civil/commercial multispectral satellite systems. These systems operate in multiple bands, can provide

ground resolution on the order of ten meters, and support multiple applications. Military applications of multispectral imaging abound. The US Army is busily incorporating MSI into its geographic information systems for intelligence preparation of the battlefield or "terrain categorization" (TERCATS). The Navy and Marines use MSI for near shore bathymetry, detecting water depths of uncharted water ways, to support amphibious landings and ship navigation. MSI data can be used to help determine "go, no go and slow go" areas for enemy and friendly ground movements. This information can be especially useful in tracking relocatable targets such as mobile short range and intermediate range ballistic missile launchers by eliminating untrafficable areas. Using MSI data in the radar, Infra-Red (IR) and optical bands, environmental damage caused by combat (or natural disasters) can be more quickly discerned. For example, LANDSAT imagery helped determine the extent of damage caused by Iraqi-set oil fires in Kuwait during the Gulf War.[11]

Although MSI has a variety of uses and many advantages, this sensing technique results in a decrease of both bandwidth and resolution from conventional spectrometry. Additionally, multispectral systems cannot produce contiguous spectral and spatial information. These disadvantages must be overcome to meet the surveillance and reconnaissance needs of the warfighter and commander of 2020.

Hyperspectral Sensing

One promising technology for overcoming these shortfalls is hyperspectral sensing. Hyperspectral devices can produce thousands of contiguous spatial elements of information simultaneously. This would allow for a greater number of vector elements to be used for such things as space object identification, resulting in higher certainty of object identification. Although hyperspectral models do exist, none have been optimized for missions from space, nor integrated with the current electro-optical, infra-red, and radar imaging technologies.

This same technology can be equally effective for ground target identification. Hyperspectral sensing can use all portions of the spectrum to scan a ground target or object, collect bits of information from each band, and fuse the information to develop a signature of the target or object. Since only a small amount of information may be available in various bands of the spectrum (some bands may not produce any

information), the process of fusing the information and comparing it to other intelligence and information sources becomes crucial.

There are several warfighting needs for a sensor providing higher fidelity and increased resolution to support, for example, USSPACECOM and its components' missions of space control, space support, and force enhancement. In addition to the aforementioned examples of deep space object identification (either from ground or a space platform), identification of trace atmospheric elements, and certain target identification applications, there are also requirements in the following areas: debris fingerprints, damage assessment, space object anomaly identification (ascertaining the health of deep space satellites), spacecraft interaction with ambient environment, terrestrial topography and condition, and environmental treaty verification.

There are several enabling technologies involved in surface, air, and space object identification. These include, but are not limited to: remote calibration (ground-to-space or ground-to-ground), extreme sensitivity detectors, algorithms for very low signal to noise ration conditions, multiple frequency laser imaging and range devices (LIDARSs) enabling precise frequency control and stability.

Several technologies are currently being developed that can be integrated into hyper-spectral sensing to further exploit ground and space object identification. Two promising technologies include remote ultra low light level imaging (RULLI) and fractal image processing. RULLI is a Department of Energy initiative to develop an advanced technology for remote imaging using illumination as faint as star light.[12] It encompasses leading edge technology that combines high spatial resolution with high fidelity resolution. Long exposures from moving platforms become possible because high-speed image processing techniques can be used to de-blur the image in software. RULLI systems can be fielded on surface-based, airborne, or space platforms, and when combined with hyperspectral sensing, can form contiguous continuous processing of spatial images using only the light from stars. This technology can be applied to tactical and strategic reconnaissance, imaging of biological specimens, detection of low-level radiation sources via atmospheric fluorescence, astronomical photography in the x-ray, UV and optical bands, and detection of space debris. RULLI depends on a new detector--the crossed-delayed line photon counter--to provide time and spatial information for each detected photon. However, by the end of FY-96, all technologies should be sufficiently developed to facilitate designing an operational system.

The task of finding mobile surface vehicles requires rapid image processing. Automated pre-processing of images to identify potential target areas can drastically reduce the scope of human processing and provide the warfighter with more timely target information. Hyperspectral sensing can aid in quickly processing a large number of these images on-board the sensing satellite, identifying those few regions with a high probability of containing targets, and down linking data subsets to analysts for visual processing. The topological features of natural terrain (sand dunes, ocean surface, forests) are characterized by irregular shapes whereas man-made objects (missiles, vessels, vehicles) contain regular features with sharp edges and straight lines. A numerical quantity called the fractal dimension, "D", can be computed from an image of natural terrain. If a man-made object is superimposed onto the natural terrain background, the value of "D" changes noticeably. Therefore, an image could be characterized as completely natural or as containing a man-made object by obtaining the value of "D." By placing this processing capability on-board a satellite, the pre-processed imagery could be fused with other sensory information or simply down linked to national and theater-level analysts. Although fractal-like backgrounds can be defeated by cloud/smoke-cover or camouflage, if fused with information from other sensory sources, it can help the analyst or the processing software identify ground based signatures.[13]

Hyperspectral sensing offers a plethora of opportunities for deep space and ground object identification and characterization to support the warfighter's space control and surveillance mission, remote sensing of atmospheric constituents and trace chemicals, and enhanced target identification. Collecting and fusing pieces of information from each band within the spectrum can provide high fidelity images of ground or space based signatures. Moreover, when combined with fused data from other sensory and non-sensory sources, it can provide target identification that no single surveillance system could ever provide. The result: The warfighter has a much improved picture of the battle space--anywhere, anytime.

Acoustic Sensing

When matter within the atmosphere moves, it displaces molecules and sends out vibrations or waves of air pressure that are often too weak for our skin to feel. Waves of air pressure detected by the ears are called sound waves. The brain can tell what kind of sound has been heard from the way the hairs in the inner ear vibrate. Ears convert

pressure waves passing through the air into electrochemical signals which the brain registers as a sound. This process is called acoustic sensing.

Electronically-based acoustic sensing is not very old. Beginning with the development of radar prior to W.W.II, applications for acoustic sensing have continued to grow, and now include underwater acoustic sensing known as sonar, ground and subterranean-based seismic sensing, and the listening to communications and electronic signals from aerospace. Electromagnetic sensing operates in the lower end of the electromagnetic spectrum and covers a range from 30 hertz to 300 gigahertz. Acoustic sensors have been fielded in various mediums, including surface, subsurface, air and space. Since the advent of radar, most acoustic sensing applications have been pioneered in the defense sector. Space-based acoustic sensing developments in the Russian defense sector have recently become public.

According to The Soviet Year in Space 1990:

> Whereas photographic reconnaissance satellites collect strategic and tactical data in the visible portion of the electromagnetic spectrum, ELINT (Russian defense electronic intelligence) satellites concentrate on the longer wavelengths in the radio and radar regions... Most Soviet ELINT satellites orbit the earth at altitudes of 400 to 850 kilometers, patiently listening to the tell-tale electromagnetic emanations of ground-based radar's and communications traffic.[14]

It is believed the Russians use this space-based capability to monitor tactical order of battle changes, strategic defense posture and treaty compliance.

On the ground, the United States used different kinds of acoustic sensors during the Vietnam War. The first was an acoustic sensor derived from the sonobuoy developed by the US Navy to detect submarines. The USAF version used a battery-operated microphone instead of a hydrophone to detect trucks or even eavesdrop on conversations between enemy troops. The air-delivered seismic detection (ADSID) device was the most widely used sensor. It detected ground vibrations by trucks, bulldozers, and the occasional tank, though it could not differentiate with much accuracy between vibrations made by a bulldozer and a tank.[15]

In the civil sector, there are numerous examples of applications of acoustic sensing. In the United States, acoustic sensors that operate in 800-900 Hz range are now being developed to help in detecting insects. It is conceivable that these low volume, acoustic sensors could be further refined to either work hand-in-hand with other spectral sensors or by themselves to classify insects and other animals based on noise characteristics.[16]

Sandia National Laboratory in New Mexico has made progress in using acoustic sensors to detect the presence of chemicals in liquids and solids. In the non-laboratory world, these acoustic sensing devices could be used as real-time environmental monitors to detect contamination either in ground water or soil, and have both civil (e.g., natural disaster assessment) and military (e.g., combat assessment) applications.[17]

An additional development in the area of acoustic sensing revolves around seismic tomography to "image" surface and sub-surface features. Seismic energy travels as an elastic wave that is both reflected from and penetrates through the sea floor and structure beneath--as if we could see the skin covering our face and the skeletal structure beneath at the same time. Energy transmitted through the crust can also be used to construct an image.[18]

In summary, acoustic sensing offers great potential for helping the warfighter, commander, and war planner of the 21st century solve the problems of target identification and classification, combat assessment, target development, and mapping. For acoustic sensing from aerospace, a primary challenge appears to be in boosting noise signals through various mediums. Today, this is accomplished using bistatic and multistatic pulse systems. In the year 2020, assuming continued advances in interferometry, the attenuation of electromagnetic "sound" through space should be a challenge already overcome, thus permitting very robust integration of acoustic sensing with other remote sensing capabilities from aerospace.

A more serious 2020 challenge in defense-related acoustic sensing may come from enemy countermeasures. As operations and communications security improve, space-based acoustic sensing will become increasingly more difficult. Containing emissions within a shielded cable or better yet, a fiber optic cable, makes passive listening virtually impossible. The challenge for countries involved with space-based acoustic programs is to develop improved countermeasures to overcome these

technological advancements. In the year 2020, remote acoustic sensing from space and elsewhere will be a critical element for developing accurate structural signatures as well as for assessing activity levels within a target. New methodologies for passive and active sensing need to be developed and should be coupled with other types of remote sensing.

Olfactory Sensing

Although this sense is somewhat "exotic" today, since the mid 1980's there has been a resurgence of research into the sense of smell. Both military as well as civilian scientists have aimed their efforts at first identifying how the brain determines smell and how we could synthetically replicate the process. The results of these efforts are impressive. An electronic "sniffer" that can analyze odors needs two things: 1) the equivalent of a nose to do the smelling, and 2) the equivalent of a brain to interpret what the nose smelled. A British team employed arrays of gas sensors made of conductive polymers working at room temperature. Each sensor has an electrical current that passes through it. When odor emissions collide with the sensors, the current changes and responds uniquely to different gases. The next step was to synthesize the various currents into a meaningful pattern. Using a neural net (a group of interconnected microprocessors that simulate some basic functions of the brain) the patterns were identified. The neural net was able to learn from experience and did not need to know the exact chemistry of what it was smelling. It could recognize when patterns changed, giving it a unique ability to either detect new or remove substances.[19]

Swedish scientists took this a major step further. Their development of a light-scanned, seam-conductor sensor shows great promise in the area of long range sensing. This sensor is coated with three different metals: platinum, palladium, and iridium. These elements are heated at one end to create a temperature gradient. This allows the sensor to respond differently to gasses at every point along its surface. The sensor is read with a beam of light which generates an electrical current across the surface. The current, when fed into a computer, results in a unique image of each smell which is compared to a data base to determine the origin.[20]

Despite these impressive findings, present technology requires the gases to physically come in contact with the sensor. The next step is to physically fuse the sensory capabilities into a sort of particle beam which when coming into contact with the odors would react in a measurable way. Similar to radar, beam segments would return to

the processing source and the object from which the odors emanated would be identified. This process could be initiated from space, air or land and would be fused with other remote sensing capabilities to build a more complete picture. Studies on laser reflection demonstrated the ability to correct for errors induced by moving from the atmosphere to space. There is every reason to believe that the next couple of decades will produce similar capabilities for particle beams. The ability to fuse odor sensors within these beams and receive the reactions for processing may also be feasible in the prescribed time frame.

Gustatory Sensing

Another area that has not received a tremendous degree of attention is the sense of taste. In many ways, ideas concerning the sense of taste may sound more like the sense of smell. The distinction is that the sample tasted is part of (or attached to) a surface of some sort. The sense of smell relies on airborne particles to find their way to receptors in the nose. The study of taste makes frequent reference to smell--this is probably due to similar mechanisms where the molecules in question come in contact with the receptor (be they smell or taste receptors).

Taste in and of itself will probably not be a prime means of identification. It can, however, be one of the discriminating bits of information that can aid in identifying ambiguous targets identified by other systems. It also provides another characteristic that must be masked or spoofed to truly camouflage a target. Taste could be used to detect silver paint that appears to be aluminum aircraft skin on a decoy. It could be used to "lick" the surface of the ocean to track small polluting craft. It could even be used to taste vehicles for radioactive fallout or chemical/biological surface agents. We could detect contamination before sending ground troops into an area. By putting a particular flavor on our vehicles, a taste version of IFF may be possible.

The sense of taste provides the human brain with information on characteristics sweetness, bitterness, saltiness, and sourness. The exact physiological mechanism for determining these characteristics is not yet completely understood. It is theorized that sweet and bitter are determined when molecules of the substance present on the tongue become attached to "matching" receptors . The manner in which the molecules match the receptors is believed to be a physical interlocking of similar shapes such as how pieces of a jigsaw puzzle fit together. Once the interlocking takes place, an electrical impulse is

sent to the taste center in the brain. It is not known whether there are thousands of unique taste receptors (each sending a unique signal), or if there are only a few types of receptors (resulting in a many unique combinations of signals). The experts think saltiness and sourness are determined in a different manner. Rather than physical attachment to the receptors, these tastes "flow" by the tips of the taste buds, exciting them directly through the open ion channels in the tips.[21]

To make a true bitter/sweet taste sensor in space would require technology permitting the transmission of an actual particle of the object in question. This appears to be outside the realm of possibility in the year 2020. An alternative would be to scan the object in question with sufficient "granularity" to determine the shape of the individual molecules, and then compare this scanned shape with a catalog of known shapes and their associated sweet or bitter taste. Such technology is currently available in the form of various types of scanning/tunneling electron microscopes. The shortcoming of these systems is they require highly controlled atmospheres and enclosed environments to permit accurate beam steering and data collection. The jump to a "remote electron microscope" may also be outside the reach possible by 2020.

Alternate means of determining surface structure remotely could be to increase the distance from which Computerized Axial Tomography (CAT) scans or Non-Magnetic Resonances (NMR)[22] are conducted. While current technology requires rather close examination (on the order of several inches), at least a portion of the "beam" transmission takes place in the normal atmosphere. Extrapolation of this capability to be able to scan from increased distance does seem possible.

To perform something such as a taste scan from space to determine the sweet/bitter taste of an object will require continued research and a truly great increase in technology. First of all, taste research must continue and the mechanics of taste must be fully understood. From this research, the appropriate characteristics of molecules related to taste would need to be cataloged in a database. Without the understanding of how taste works, a scanner could not be designed properly.

The problem of remote scanning is the second great challenge and it comes in two parts: getting the beam to the targeted object; and capturing the reflected beam pattern to determine the surface shape at the molecular level. Getting the beam to the target has three prerequisites: beam generation, beam aiming, and beam power.

The scanning beam (of whatever type provides the desired granularity) needs to be generated with sufficient power to reach the target with enough energy to reflect a detectable and measurable pattern for collection and subsequent analysis. Beam generators and collectors are expected to both be located (not necessarily co-located) in space (most likely a low earth orbit [LEO] at least for the generators). Maximum distance from generator to target is probably on the order of 1000 to 1500 miles or the slant range from a 300-400 mile LEO to the line of sight horizon. Target to collector distances would be at a minimum the same as generator to target (if collection is accomplished in LEO) to a maximum of 25,000 miles (if collection is accomplished in geosynchronous orbit.)

To ensure data being gathered is what is desired, the beam must be aimed and focused exactly at the desired target. Aiming will require compensation for atmospheric inconsistencies. Work has already been done in this area where a laser is fired into the atmosphere to detect anomalies along the general path of the actual beam. This information is used to refine the final aiming to the target to properly compensate. Refined focusing on the targeted areas should be on the order of no more than 1 or 2 square feet. This sample size should control the number of different tastes sensed to a reasonable number while still being large enough too keep the required number of samples relatively low.

Associated with beam power is the consideration of what happens when the beam (of whatever type) hits the target area. Will the power required be so great as to burn or damage the target? Will the scanning be detectable in the target area? These challenges must be overcome in order to bring the taste sensor to reality.

Capturing the reflected beam is also a significant challenge. The general technique used to analyze objects with scanning methods calls for a beam from a known location and of known power to "illuminate" the targeted object. Since the surface of the object is irregular, the beam is reflected in various directions. For this reason, the object needs to be virtually surrounded by collectors to insure all reflected energy is collected. By virtue of which collector collects which portion of the beam, the surface reflecting the beam can be reconstructed.

In much the same way that beam aiming is a challenge due to the inconsistencies of the transmission medium between the beam generator and the target, collection of the reflected beam is also challenging.

Since it is impossible to completely surround the earth with a single collecting surface, a large number of platforms must serve as collectors. To provide reasonable capability for collecting the reflected energy for analysis. All platforms would need to focus their collectors on the targeted area by compensating in a manner similar to the beam generator. Platforms available for collection would be any with line of sight directly to the target as well as any "below" the physical horizon but who may be able to capture reflected energy in a manner similar to over the horizon back scatter (OTHB) radar system. With appropriate algorithms and beam selection, it is conceivable that the entire sensor constellation could be available for collection all the time.

Fusing of the reflected data from a single "taste" would take place on a central platform, probably in geosynchronous orbit. Information about the taste measurement would include scanning beam composition, pulse coding data, firing time, location of beam generator, aiming compensation data, focusing data, targeted area location, collector position, collector compensation data, and actual collected data time of collection and pulse coded data. All this data is needed to accurately assemble the data collected in many locations at slightly different times. Basically we are collecting only a fraction of the "reflected energy" from scanning beams and all this information is needed to know which part of the "taste signature" we have put together.

Tactile Sensing

The final sense examined is the sense of touch, or tactile sensing. A potential exists for the development of an earth surveillance system using a tactile sensor for mapping and object determination. Rather than viewing and tracking items of interest optically, objects could be identified, classified and tracked via tactile stimulation and response analysis. This method of surveillance has advantages over optical viewing in that it is unaffected by foul weather, camouflaging or other obscuration techniques.

Tactile sense provides humans with a notice of contact with an object. Through this sense, we learn the shape and hardness of objects, and using our cutaneous sensors we receive indications of pressure, warmth, cold and pain. A man-made tactile sensor

emulates this human characteristic using densely arrayed elementary force sensors (or taxels) which are capable of image sensing through the simultaneous determination of a contacting object's force distribution and position measurements.[23]

Recent advances in tactile sensor applications have appeared in the areas of robotics, cybernetics and virtual reality. These simple applications attempted to replicate the tactile characteristics of the human hand. One project, the Rutgers Dexterous Hand Master, combines a mechanical glove with a virtual reality scenario to allow an operator to 'feel' virtual reality images. This research has advanced the studies of remote controlled robots that could be used in such ventures as construction of a space station or cleaning up a waste site.[24]

The challenge is to develop tactile sensors which are capable of remotely 'touching" an object to determine object characteristics. This challenge elicits visions of a large gloved hand reaching out from space to squeeze an object to determine if it is alive. This science fiction analogy can be developed by expanding the practical concept of radar.

Radar is a radio system used to transmit, receive and analyze energy waves to detect objects of interest or "targets". In addition, target range, speed, heading and relative size can be determined. One possible way to identify tactile characteristics of an interrogated target is to analyze the radar returns and compare data reception to known values. Any radio wave striking an object will have a certain amount of its energy reflected back toward the transmitter. The intensity of the returned energy depends upon the distance to the target, the transmission medium, and the composition of the target. For example, energy reflected off a tree exhibits characteristics different from those of energy reflected off a building (a tree absorbs more energy). By analyzing the energy returns, it is conceivable that target characteristics of shape, temperature, and hardness could be determined through a comparative analysis against known values. The tactile characteristics of the various objects interrogated in an area surveillance could then be transformed into a 3-dimensional graphical representation using virtual reality.

The significant value in evolving tactile sensor technology lies not in the development of a replacement for current surveillance sensors, but in the unique additional information gained. A typical surveillance radar provides the "when, where,

and how" for a particular target, while a tactile sensor adds the "what" and potentially the "who".

Countermeasures to Sensing

Once a potential adversary perceives a potential threat to its structure and system, the enemy usually develops and employs countermeasures. The concepts for sensing in this paper, albeit rooted in leading edge technology, are not exempt from enemy countermeasures. Potential enemy countermeasures in 2020 include killer ASATs, jamming, and ground station attacks. Target protection countermeasures include concealment, camouflage, and deception (CC&D) and OPSEC. Technical experts must address these threats and countermeasure early in the design phase of this sensing system.

Active and passive systems can overcome jamming, ground station attack, and enemy OPSEC. In the case of jamming, frequency hopping and "hardening" of space links are both effective countering techniques. Hopping rates currently exceed 3,000 hops per second. These rates will most likely continue to increase exponentially in the future, which could make many forms of jamming a minor irritant. Overcoming ground station attack can be accomplished through improved physical security and redundancy of critical nodes. Redundancy can be expensive, but if incorporated early in the design phase, it can be efficient and cost effective. Finally, the best way to counter enemy OPSEC is through passive measures such as better security training, HUMINT, and reducing the number of people that "need to know," and active measures such as HUMINT and exploiting the “omni-sensorial” capability of this system.

Killer ASAT and CC&D capabilities are much more difficult and costly to counter. Decoy satellites and redundancy in space-based systems can be effective. However, some cost-effective means of hardening must be pursued to ensure the survivability of our space systems. In the case of CC&D, the diversity of sensors employed, combined with other intelligence sources, should provide a counter to this threat. Techniques for employing multi-source sensing must keep pace with such emerging technologies as holographic imaging to ensure a counter to the spoofing threat is maintained.

Developing effective means to offset enemy countermeasures is a never-ending challenge. To avoid it, however, is to run the risk of developing expensive technology

that can be rendered useless or ineffective by enemy countermeasures. An advantage to studying "measures" and countermeasures simultaneously is awareness of how friendly systems can be better protected or desensitized to potential countermeasures.

Data Fusion

Fusion of all the information collected from the various sensors mentioned above is the key to taking the massive amount of data and turning it into useful information for the warfighter (See Figure 3). Without the appropriate fusion process, the warfighter will be the victim of information overload, a condition which is not much better and sometimes worse than no information at all. The ability to fuse vast amounts of multisource data, real time, and have it available to the warfighter on-demand, is the goal of this initiative.

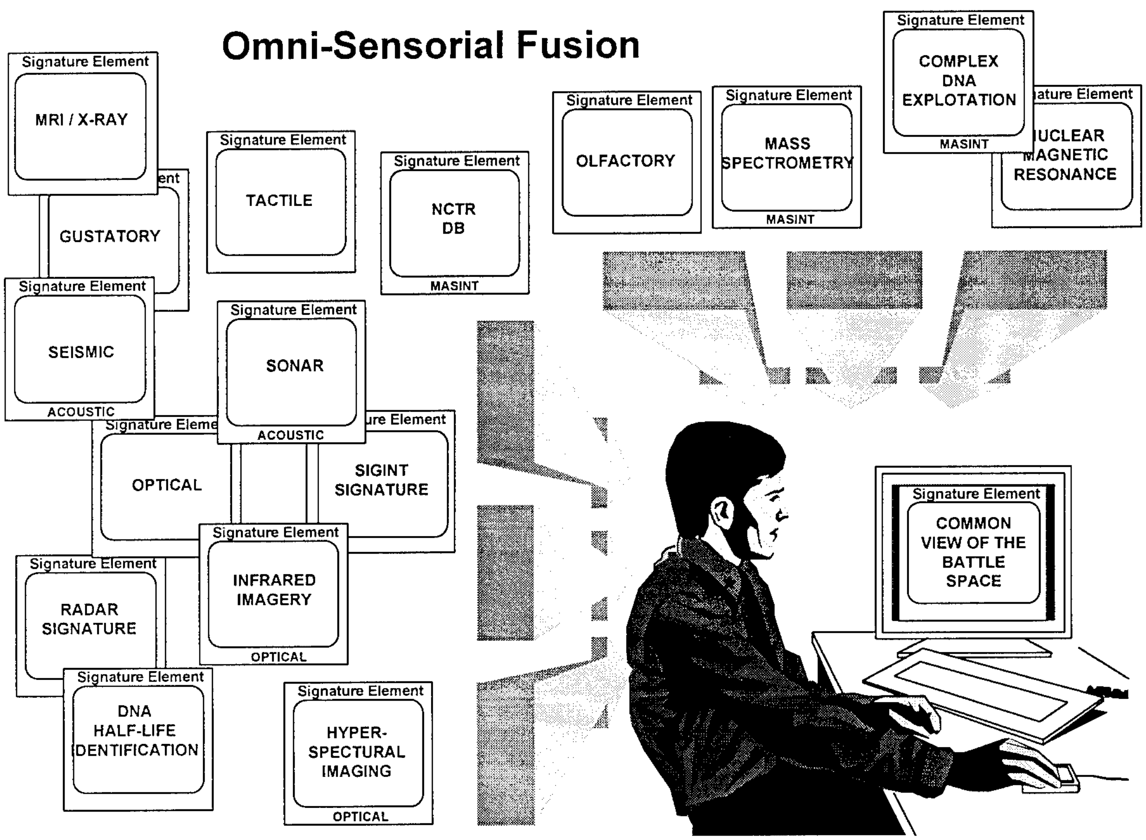

Figure 3. Omni-Sensorial Fusion

Today, we are able to collect data from a variety of sensor platforms, e.g., satellites, air breathing, HUMINT sources, etc. What we are not able to do, however, is

to fuse large amounts of multisource data in a near real time fashion. Today, we have what amounts to "stovepipe" data, that is, data streams being processed independently. As we discovered in Desert Storm, there were deficiencies in sharing and relating intelligence from different sources. The warfighter was not able to see the whole picture, just bits and pieces.

In today's environment, sensor data is capable of drowning us. The sheer volume of this data can cripple an intelligence system.

> Over 500,000 photographs were processed during Operation Desert Storm. Over its 14 year lifetime, the Pioneer Venus orbiter sent back 10 terabits (10 trillion bits) of data. Had it performed as designed, the Hubble Space Telescope was expected to produce a continuous data flow of 86 billion bits a day or more than 30 terabits a year. By the year 2000, satellites will be sending 8 terabits of data to earth each day. [25]

As staggering as this is, the computing power on the horizon may be able to digest this data. The Advanced Research Projects Agency (ARPA) is sponsoring the development of a massive parallel computer capable of operating at a rate of one trillion floating point operations per second (1 tera FLOPS). Parallel processing is the employment of multiple processors to execute several instruction streams concurrently. Using parallel processing, the time required to process information is much faster than if only one processor were doing the work.

Once the data is processed into usable information or intelligence, a means of storing and retrieving a huge database or library is needed. "Advances in storage technology in such media as holography and optical storage will undoubtedly expand these capacities."[26] An optical tape recorder capable of recording and storing more than a terabyte of data on a single reel is being explored.

Vertical block line (VBL) storage technology offers the possibility of storing data in non-volatile, high density, solid-state chips. It is a magnetic technology which offers inherent radiation hardness, data erasability and security, and cost effectiveness. VBL technology is intended to provide non-volatility, high density, and solid-state performance simultaneously. When compared to magnetic bubble devices, VBL offers higher storage density. It also offers higher data rates at reduced power when compared to bubble devices. VBL chips could achieve (volumetric) storage densities ranging from

one gigabit to one terabit per cubic centimeter. Chip data rates, a function of chip architecture, can range from one megabit/second to 100 megabits/second. Chip costs, in volume production, are estimated to be less than one dollar per megabyte.

In order to provide the user real time, multisource data in a usable format, leaps in data fusion technologies must occur. A new technology which could exponentially increase computational speeds is the photonic processor. The processing capabilities and power requirements of current fielded and planned electronic processors are determined almost solely by the low-speed and energy inefficient electrical interconnects used to interconnect electronic boards, modules, or processing systems. Processing speeds of electronic chips and modules can exceed hundreds of megahertz, whereas electrical interconnects run at tens of megahertz rates due to standard transmission line limitations. More significantly, the majority of power consumed by the processor system is used by the interconnect itself. Optical interconnects, whether in the form of free-space board-to-board busses or computer-to-computer fiber optic networks, consume significantly less electric power, are inherently robust with regards to electromagnetic impulses (EMI) and electromagnetic pulses (EMP), and can provide large numbers of interconnect channels in a small, low weight, rugged subsystem. These characteristics are critically important in space-based applications.[27]

This technology of integrating electronics and optics reduces power requirements, builds-in EMI/EMP immunity, and increases processing speeds. The technology is very immature but has great potential. If it were possible to incorporate photonic processing technologies into a parallel computing environment, increases of several orders of magnitude in processing speeds might occur.

The fusing of omni-sensorial data will require processing speeds equal to or greater than those mentioned above. On-board computer (OBC) architectures will use at least three computers, performing parallel processing and using a voting process to ensure that at least two of the three OBCs agree. The integration of neural networks in OBC systems will provide higher reliability and enhance process control techniques.

Change detection/pattern recognition and chaos modeling techniques will increase processing speeds along with reducing the amount of data to be fused. Multiple sensors, processing their own data, can increase processing speeds and share data between platforms through cross-queuing techniques. Optical data transmission techniques should

permit high data throughputs to the fusion centers in space, on the ground, and/or in the air.

The National Information Display Laboratory is investigating technologies which would aid in the registration and deconfliction of received omni-sensorial data, data fusion, and image mosaicing. "Information-rich" environments made accessible by the projected sensing capabilities of 2020 will drive the increasing need for geo-referenced autoregistration of multisource data prior to automated fusion, target recognition/identification, and situation assessment. Image mosaicing, or the ability to consolidate many different images into one, will enhance the usability of wide area imagery-based products. Signals, multiresolution imagery, acoustical data, analyzed sample data (from tactile/gustatory sensing), atmospheric/exoatmospheric weather data, voice, video, text, and graphics can be fused in an "infobase" which provides content- and context-based access, selective visualization of information, local image extraction, and playback of historical activity.[28]

An omni-sensorial distributed fusion processing capability, either on-board the sensor platform, on the ground, or in the air, will act as a strong defensive countermeasure against possible enemy threats (jamming, ASAT, lasing, etc.). The future environment will no longer permit centralized fusion centers because of their vulnerability to single-event failures either through enemy attack or natural disasters. Neural network technology offers opportunities for size, weight, and power reductions in addition to opportunities for distributed networking. Internal logical and physical arrangements of neural systems (their software and hardware) can be modeled on the massively parallel, highly distributed, and self-organizing arrangements found in the brain--a silicon-based model of a carbon-based information processing and decision mechanism refined over millions of years of life on Earth. Neural systems emulate the coordinated interactions of a living organism's neurons, synapses, and nerve pathways, using many hierarchically-related computers (data processing elements--some space-based, some land-based) and self-modifying decision software in each processing element, linked by reconfiguring networks of high speed communications channels. At any time in the system's operational life, the "strengths," structure, and interconnections of a neural system's components will determine its inferential abilities at that moment. The strength of each system connection--the degree to which each processor element can affect the inferential findings of the other processor elements in the system--is called the "weight" of that connection. At any point in time, each connection's weight is determined

by "who" the processor can currently connect to, the capacity of those channels and the type of data it can pass, and the current hierarchic position of the processor. This hierarchic connections configuration making up the system will constantly rearrange itself with the arrival of the new situational data of interest to the neural system. In this manner, the neural system is always optimally self-organized to assimilate the new input.

The architecture for neural data fusion can be described in a model consisting of two to three major sub-processor levels. The first level takes observation data from multiple sensors and associates it with a hypothesized object and background. The extent of a potential "match" to a known object or background is given a value. Optimization of the value leads to an assignment of the observation to a labeled set. The set is a group of point objects in three dimensional space without reference to any context. The second level takes the labeled set and places it within a contextually-oriented framework through a process of situation refinement (resolution of conflicting data interpretations), situation abstraction (development of relationships between observation features and actual database elements), situation assessment (composite interpretations of these relationships combined with an analysis of activities and events), and situation prediction (extrapolation of the analyses to a future point in time). The end result is a series of conditional relationships. Using table structures, object-oriented techniques, and similar recognition schemes, a solution to the observation is made by "expectation templating".

From this point the second level fusion process "results from the flow of multi-sensor data and inferences into this template structure" to confirm the match of sensory data to the template. A third level can be envisioned where strictly military data is coupled to the results from the first two levels to produce an assessment of the object of interest's ability to inflict damage, i.e. a threat assessment.[29] For example, sensor systems detect an object and determine it to be a car-like object traveling in Montana (first level process). Next, data conflicts between sensors are resolved and the type of car and details of the environment are set (situation refinement). As the car rounds a corner, the system expects the "picture" to change (situation abstraction). The expectation is confirmed against sensor data as time progresses and it is determined that the car is moving on a winding mountain road (situation assessment). Speeds, terrain, geographic location, etc., are combined to predict the car's behavior as time progresses (situation prediction). All this taken at once is second level data fusion providing a solution to the observation. A third level would be the addition of behavioral traits (threat envelopes) to determine the object's intent (See Figure 4).

Crucial to both level one and two is the ability to have a processor recognize and understand patterns (cars, faces, armored vehicles, buildings, landscapes, etc.) as an animal brain does. The animal brain relies on neurons highly interconnected in three dimensions to recognize and interpret patterns rather than bit streams as do computers. Animal brains also process information on several different levels simultaneously. Neural network technology was inspired by these biological processors. They can perform a variety of pattern mapping functions or processes. They can reconstruct a stored pattern when the input is a only a partial match for that pattern, retrieve a second pattern associated with a given input pattern, generate a new pattern based on a combination of other patterns, or

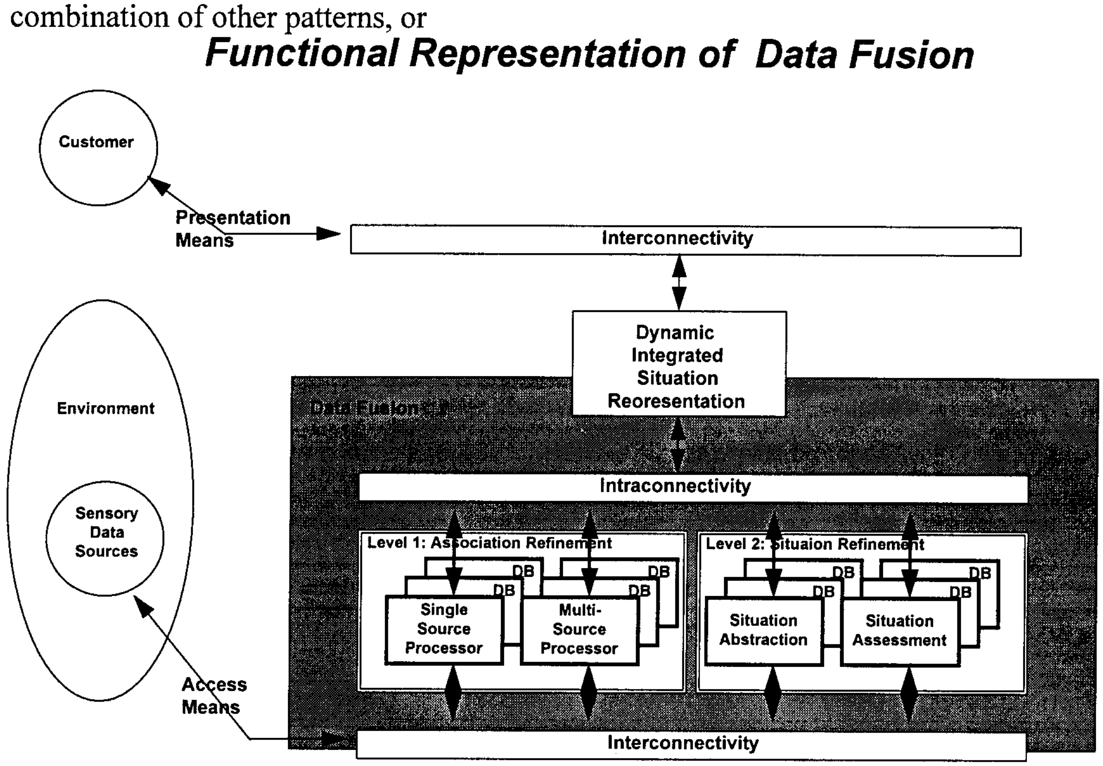

Figure 4. Functional Representation of Data Fusion

group similar patterns into clusters and provide new patterns representative of the clusters.[30] This last function gives neural networks the ability to "learn" which in turn could reduce our postulated system's reliance on conventionally stored databases such as digital terrain data, weather data, sensor system features, nuclear data, biological data, chemical data, building structure data, commercial systems characteristics data, weapon systems characteristics, and order of battle data.

Neural networks can discern patterns and trends too subtle or too complex for humans, let alone current conventional computers. They can perceive relationships among thousands of variables where as a human can only deduce the relationships among two or three variables simultaneously. Hence, these networks have the ability to identify emerging trends and draw conclusions better then humans. Neural network technology is already in use in spotting credit card fraud by identifying changes in spending patterns. Mellon Bank of Delaware discovered that credit card thieves were charging $1 dollar amounts to see if the stolen cards they were trying to use had been discovered. It could have taken weeks for human investigators using older conventional processing techniques to discover the same trends. In this case, their "just installed neural network detected this new pattern on its own, without us having told it anything about a scam." Imagine this capability in a combat environment. A network "trained" in an enemy's order of battle could not only predict enemy courses of action based on force movements detected by various sensor systems but also detect deviations from doctrine thereby alerting commanders of possible surprise attacks or deceptions. It is not difficult to imagine an operational level commander in a virtual reality environment with the battle space three dimensionally displayed all around him (or her) where friendly and hostile forces are not only depicted in traditional blue and red objects but the anticipated moves of the red objects are also indicated by a series of red arrows displayed on the battlespace. The predictive capabilities of these networks are already making a debut in the commercial world with airline companies who use them to forecast passenger loads and revenues. Networks forecast demand based on the time of day, day of the week, and season of the year. The networks have proven to be 20 percent more accurate than traditional computer based statistical predictions.[31]

IBM France built a neural system that warns of industrial robotics equipment failure and alerts maintenance technicians before a failure occurs. The sounds, vibration and other sensory data of a normally working motor and those of a malfunctioning motor are "shown" to the system. The system then monitors the motor(s) and based on the earlier example it detects changes and predicts problems. Furthermore, each instance becomes another example. The system learns as it works.[32] Current neural network technology is limited by the fact that the systems using it are essentially simulations using traditional software, hardware, and metallic interconnections.

Multilayer back-propagation network (MBPN) is the most common and capable neural system approach under research today. This approach shows great promise for further development and maturation. Human programmers do not specify in advance the internal rules and procedure for a MBPN-based system. Instead, the neural system's expertise is represented by the changing patterns of activation and current connection weights exhibited by the current connection configuration in the system--analogous to the brain's constant synapse firings. In order to determine a response, MBPN systems require only that the inferential problem be represented in terms of an input data vector representing the current situation for each connection and an associate output data vector for expressing the finding or result to another connection or (finally) the warrior.

To achieve a "proper" set of internal connection weights and activation's, MBPN-based neural systems must be initially "trained" through exposure to historical examples of situation observations and correct performance outcomes (using associated data inputs and data outputs). During the system training, the historical example sets are used to expose the system to the values of the input and output vectors, which are then "clamped" to specific processing elements of the neural system as their activation or reaction levels. Through a repeated series of associated input and output examples (training sessions), the clamped activation levels methodically influence and adjust the remainder of the system's connections until a generalized solution is achieved (a mapping between the inputs and outputs is found)--the system has "learned" to recognize, analyze, and respond to similar (but not identical) situations. In this manner, MBPN-based neural systems are trained to associate collections of input data and desired output result(s) by being taught the differences between the actual result it produces in each training session and the result desired by the system's "teachers." To the teachers, system training means repeatedly presenting the system with correct examples of associated input and output data vectors and allowing the system to internally adjust itself until a mapping error occurs. Thus is remarkably analogous to what we understand about the human learning experience--learning by mistakes.

The fully-trained neural system or fully-developed AI system is limited to producing a response based on situational data similar to that presented in its training/experience or its "if-then" logic tables--this is an essential drawback of these systems. The systems can relate only to what they have been taught or programmed to recognize, and then they can only respond in a predetermined manner. For any MBPN-based neural system, the human-selected input and output data vectors selected for its

training embody the same risks and rewards as the "knowledge engineering" required for an AI system. The ultimate success of a neural system (making roughly the same decision a human expert would make under similar conditions) depends on the set(s) of data used to initially train the system and the system's experience in real world situations up to that point. High capacity data transfer schemes can speed the training to a point that the system is highly effective once deployed. Its ability to continue to learn ensures it effectiveness with each new experience after deployment. The limits to the depth of learning that can conceivably take place are incalculable and will bounded only by the systems capacity to store, network, and process information. All of these are limited today by the use of inanimate components composed of silicon and metal.

Exponential advancement will come from replacing metallic connections with chemical ones, embedding or growing actual neurons or their operative chemical parts on an artificial substrate, and connecting them to thousands of sensory inputs and virtual reality presentation systems. Efforts at the Naval Research Laboratory (NRL), Washington DC; Science Applications International Corporation (SAIC), McLean VA; the National Institutes of Health (NIH), Bethesda MD; and the University of California, Irvine CA, are joining in cooperative research that will "introduce power into organically grown neurons on artificial substrates, signal input and output, measure differences in potential, and determine ion concentrations". These are the first steps toward interfacing biological units with solid-state devices to produce working systems. SAIC's corporate vice president for advanced technology programs, Clinton W. Kelly III, predicts that "if we understand the chemistry, we can get the large molecules to perform computation and, in principle, develop devices that are lighter, more complex and that will not use nearly the power of silicon based machines".[33]

Key to producing such systems is the ability to use microelectronics fabrication techniques with advanced surface chemistry processes to layout molecular patterns that can self orient, organize, survive, and flourish. Cells are currently being grown on various materials and continually improving techniques are able to control both cell patterns and growth of the neurons' communicating cell appendages, neurites. Bioelectronic circuit design is now a potential reality. Dr James J. Hickman (SAIC), a surface chemist, and Dr David A Stenger (NRL), a biophysicist, predict that in 20 years, the bioelectronic approach could lead toward an extremely fast machine that might match or correspond with the human operator's intellect. These devices will easily learn without conventional training algorithms (needed to for simulated neural systems) and require

minute amounts of energy.[34] Super computers are expected to have only the cognitive abilities of a chicken by the end of the century.[35] It is easy to see how basketball-sized bioelectronic neural systems with near-human intellect and fully interconnected to a suite of sensors could provide phenomenal surveillance, reconnaissance, and intelligence analysis by the year 2020. Such systems would not only provide information but would determine what data was needed from what sources in what sequence in order to provide the clearest "picture" possible to the war-fighting customer.

Near-term Technologies and Operational Exploitation Opportunities

Pursuit of non-military omni-sensorial applications in the early stages of development could provide a host of interested partners, significantly reduce our cost and increase the likelihood of Congressional acceptance. These applications can be divided down into the three sub-areas of government use, consumer use and general commercial use.

Government uses of this capability could include law enforcement, environmental monitoring, precise mapping of remote areas, drug interdiction and providing assistance to friendly nations. The capability to see inside a structure could prevent incidents like the one that occurred at the Branch Davidian compound in Waco, Texas in 1993. Drug smuggling could be identified by clandestinely subjecting everyone to remote sensing. Friendly governments could be provided with real time detailed intelligence of all insurgency/terrorist operations within their countries. Finally, the spread of disease might even be tracked to allow early identification of infected areas in a way similar to how we track bird migratory patterns today using LANDSAT multi-spectral imagery.

Consumer uses would range from home security to monitoring food and air quality, as well as entertainment spin-offs. Home detection systems would be cheaper and more capable, not only able to sense smoke and physical break-ins, but gas leaks and seismic tremors. They could also provide advance warning of flash floods and other imminent natural disasters. Sensors could identify spoiled food items. Even the air we breathe could be constantly sensed to provide health benefits. The spin-offs in the field of entertainment are limited only by the imagination.

Commercial uses could include a follow-on to the air traffic control system, mineral exploration improvements, airport security and major medical advances. Farmers to miners would benefit from remote sensors minimizing the trial and error approach that often occurs today. Aircraft would be scanned before leaving their gates and before take-off to provide new levels of safety. Finally, in the medical field patients would be scanned and the data fed into a computer. Exploratory surgery would cease to exist as doctors would see any problem on screen. They would then treat the problem to include surgery and drugs on the computer image to determine the best course of action and then treat the patient knowing how the patient should react.

A good example of a commercial application is the development of a new air and space traffic control system. This system would create an aerospace traffic location and sensing (*ATLAS*) system analogous to the current air traffic control system. The environment of space is becoming more and more crowded (accumulation of satellites, debris, etc.). It is hazardous today, and will be even more hazardous as the year 2020 approaches, to fly in space without having an "approved" flight plan, particularly in LEO. The space shuttle, for instance, occasionally makes unplanned course corrections in order to avoid debris damage. Similarly, as the boundaries between space and atmospheric travel become less distinct (e.g., trans-atmospheric vehicles), this system could conceivably integrate all airborne and space transiting assets into a seamless, global, integrated system.

This system envisions that some of the same satellites used as part of the integrated *structural sensory signature* system would also be used for *ATLAS*. It would require only a small (<20) constellation of space surveillance satellites orbiting the globe. *ATLAS* satellites would carry the same omni-sensorial packages capable of tracking any object in space larger than 2 centimeters. All satellites deployed in the future would be required to participate in the *ATLAS* infrastructure. The satellites will carry internal navigation and housekeeping packages, perform routine station-keeping maneuvers on their own, and would constantly report their position to *ATLAS* satellites. Only anomalous conditions (e.g., health and status problems, collision threats, etc.) would be reported to small, satellite-specific ground crews. *ATLAS* ground stations (primary and backup) would be responsible for handling anomalous situations, coordinating collision avoidance maneuvers with satellite owners, authorizing corrective maneuvers, and coordinating space object identification (particularly threat identification). The satellite constellation would be integrated via crosslinks allowing all *ATLAS*-capable satellites to share information. The aerospace traffic control system of the future would eliminate or downsize most of the current satellite control ground stations as well as the current ground based space surveillance system. Elements of the *ATLAS* system will include improved sensors for space objects (including debris and maneuvering target tracking), software to automatically generate and deconflict tracks and update catalogs, and an analysis and reporting "back end" that will provide surveillance and intelligence functions as needed. Air and space operators would have a system where they could enter a flight plan and automatically receive preliminary deconflicted clearance. In addition, ongoing, in-flight deconfliction and object avoidance would also be available without operator manipulation. It could integrate information from even more sophisticated

sensors of the future, such as electro-magnetic, chemical, visible, and omni-spectral. "Hand-offs" from one sector to another would occur, but only in the on-board *ATLAS* brain, which would be transparent to the operator. *ATLAS* provides a vision of a future generation smart system that integrates volumes of sensory information and fuses it into a format that gives the operators just what they need to know on a timely basis. (For more information on *ATLAS*, see the Space Traffic Control white paper)

The ATLAS system is just one small commercial application of the comprehensive *structural sensory signature* concept that fuses data from a variety of sophisticated sensors of all types to provide the warfighter of tomorrow with the right tools to get the job done.

Conclusion

The precision that technology offers will change the face of warfare in 2020 and beyond. Future wars will not rely so much on sea, land, or air power as on information. The victor in the war for information dominance will most likely be successful in the battle space. The key to achieving information dominance will be the technology employed in the area of surveillance and reconnaissance, particularly, a "sensor to shooter" system that will enable "one shot, one kill" combat operations. A network of ground and space-based sensors reflecting the human senses and hyperspectral and fractral imagery provides a diverse array of surveillance information that, when processed by intelligent, robust neural networks, can not only identify objects with a high degree of reliability, but give the warfighter the sensation of being in or near the target area. The challenge for decision makers will be to develop a strategy that can turn this vision into reality. The following visionary scenario provides a mental image of the key concepts proposed in this paper (See Annex).

Annex

(3 December, 2020--YOU ARE THERE) "It had been five minutes since the tingling sensation in her arm had summoned her from her office. Now she was standing alone in the darkened battle assessment room wondering how she would do in her first actual conflict as CINC. "Computer on, terrestrial view" she snapped. Silently a huge three dimensional globe floated in front of her. "Target Western Pacific, display friendly

and enemy orders of battle, unit status and activity level", was the next command. The globe turned into a flat battle map showing corps, division, and battalion dispositions. Lifelike images appeared before her marking the aircraft bases with smaller figures showing airborne formations. Beside each symbol were the unit's designator, its manning level, and the plain text interpretation of its current activity. The friendly forces were shown in blue and the enemy in red. All the friendlies were in the midst of a recall. The map showed two squadrons of air domination drones, a wing of troop support drones, and an airborne command module (ACM) heading toward the formations of enemy forces. Shaded kill zones encircled each formation. Enemy forces floated before her also displaying textual information. The image displayed enemy units on the move from their garrisons. Speed, strength, and combat radii were marked for each unit. Some enemy units showed still in garrison but with engines running, discovered by sensitive seismic, tactile and fume smelling sensors. "Manchuria", came the next command. The map changed. The CINC was now in the middle of a holographic display. Ground Superiority Vehicles (GSVs), identified by the reliable Structural Sensory Signature System (S^4) moved below her and drones flew around her. She could see her forces responding to the enemy sneak attack and monitored their progress. The engagement clock showed ten minutes to go before the first blue and red squadrons joined in battle.

Aboard the ACM, the aerospace operations director observed the same battle map the CINC had just switched off. By touching the flat screen in front of him, his dozen controllers received their target formations. Each controller wore a helmet and face screen that "virtually" put him just above the drone flight he maneuvered. The sight, feel, and touch of the terrain profile, including trees, buildings, clouds, and rain, were all there as each pressed to attack the approaching foe.

On the ground, a platoon sergeant nervously watched his face-shield visual display. From his position he could see in three dimensional color the hill in front of him and the enemy infantry approaching from the opposite side. If the Agency had enough time before the conflict, they could have loaded DNA data on the opposing commander into the Data Fusion Control Bank (DFCB) so he could positively identify him now, but such was the fog of war. The driving rain kept him from seeing ten feet in front of him, but his monitor clearly showed the enemy force splitting and coming around both sides of the hill. The enemy's doctrinal patterns indicated that his most likely attack corridor would be on the eastern side of the hill. Now the enemy was splitting his force in hopes

of surprising our forces. The platoon sergeant's troop commander saw the same screen as her troops did with the added feature of having her opponent's "predicted" moves overlaid with his actual movements. From her virtual command post, she arrayed her forces to flank the foe. She had to be careful not to be fooled by the holographic deception images put in place by the enemy, an all too frequent and disastrous occurrence in the last conflict. If she was lucky, surprise would be on her side today.

A scant five minutes had passed since the Global Surveillance, Reconnaissance, and Targeting (GSRT) system alerted the CINC of unusual activity on the other side of the border. Multiple sensors, some of which had been dormant for years and some that had recently been put in place by special precision guided munitions(PGM) delivery vehicles, had picked up increased signal activity and detected an unusual amount of motion, scent, heat, noise, and motor exhaust in and around enemy bases. Now GSRT activated two additional CINCSAT low earth orbit multi-sensor platforms, launched four air breathing sensor drones, and fired two "light-sat" intersystem omni-sensorial communications satellites into orbit to bolster the surveillance grid that watched the globe and space beyond twenty-four hours a day. As the CINC, airborne controller, and ground troop activated their situation assessment system (SAS), GSRT identified them, confirmed their locations, and passed information required to get them on line. As each warrior requested target data, GSRT fused sensor data, tapped data bases, activated resources, and passed templated neurally collated information to each person in exactly the format they needed to get a clear picture of their enemy and the unfolding situation. This was the same GSRT that was also aiding San Francisco in responding to yesterday's massive earthquake. From the President to the city mayor to the fireman trying to find the best route through the cluttered and congested streets, each got the real-time information they asked for in seconds just as our troops in the Western Pacific did.

The CINC paused for several moments, wondering how battles were ever fought without the information systems she now used with practiced ease and she was glad they were fighting an enemy still mired in the visual/ELINT oriented maneuver force of the last war.

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NAVIGATION AND DATA FUSION FOR THE 21st CENTURY

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SPACE TRAFFIC CONTROL

The Culmination of Improved Space Operations

Subject And Problem Statement

> Space is becoming unmistakably more multilateral in character. The number of satellites in GEO (high altitude) is likely to double in the next ten years... Continued growth in the number of spacecraft will amplify the risks of ambiguities and potential accidents and generate further requirements for effective cooperation in space surveillance... *The United States must improve our spacetracking and surveillance capabilities in space.*
>
> William J. Perry, Brent Scowcroft, Joseph Nye, Jr., and James Schear
> The Aspen Strategy Group, 1985[1]

> Any worthwhile change in launch philosophy will also dictate a fundamental shift in the existing satellite design mindset... We need to move away from one-of-a-kind satellites, satellites requiring unique control networks and extensive modifications to designated launch boosters, toward satellite payloads based on customer-defined mission requirements, launched with minimal modification on standard boosters and controlled through existing networks.
>
> General Charles A. Horner,
> USAF, Commander in Chief, USSPACECOM
> Testimony to the Senate Armed Services Committee, 22 April 1993[2]

These two quotes seem unrelated, but in fact they are linked very strongly and provide the two anchors for this paper. The linkage is embodied in a concept called space traffic control, which is modeled in part on the air traffic control system. In addition to providing the space tracking and surveillance improvements urged by the Aspen Group, a properly designed space traffic control system requires an overarching operational concept (suggested by General Horner) affecting the way space vehicles are designed and employed. This connection between space object control and space operations is key to understanding the vision outlined in the pages that follow.

Leaping forward to the worlds envisioned by the SPACECAST 2020 Alternative Futures, you'll find significantly greater numbers of spacecraft competing for limited space and precious pieces of the electromagnetic spectrum. Motorola's IRIDIUM galaxy and Bill Gates' 800+ communication satellite constellation are only the opening gambits in a rush to space that may result in satellite proliferation orders of magnitude greater than anything foreseen by the Aspen Group in 1985. This explosion in the number of satellites will create increasing numbers of conflicts between the vehicles--and their Earth-bound owners. Assuming advancements in miniaturization, better lift capability, significant technology breakthroughs, or huge commercial demand, the rush to space could be overwhelming. Without a system for fused organization and deconfliction of space vehicles, conflicts caused by crowding will reach critical mass. In sum, space will likely become a very busy place (figure 1).

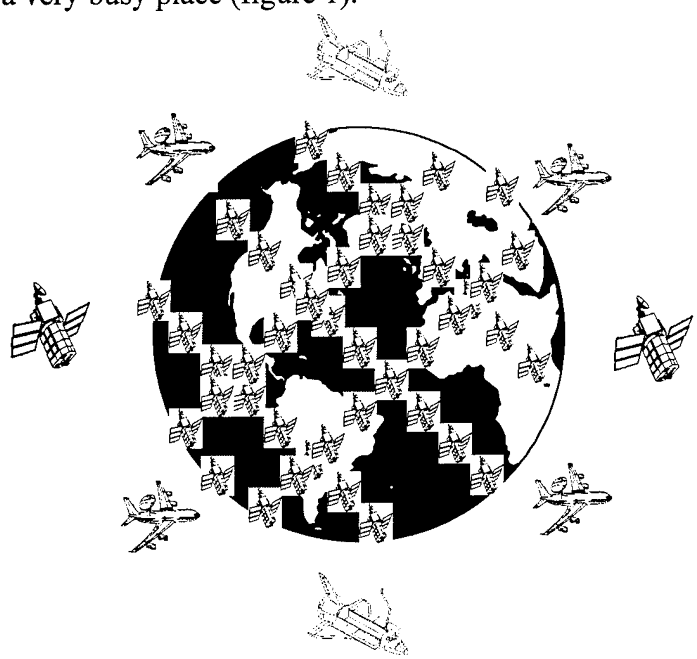

Figure 1. The Aerospace Environment in 2020: A Busy Place

Who will monitor, regulate, and provide stability for all these hurtling pieces of high technology? The US currently leads the world in the ability to track and monitor space objects, but the system is old, costly, Earth-based, and manpower-intensive. It holds too little potential for the situational awareness or operational agility required in the future. This paper proposes that we avoid the deer crossing syndrome, wherein government mandates the number of deer that must be killed on a given stretch of road

before a sign is erected. Building a proper space traffic control system will put up the sign before satellite conflicts become a major issue.

Space vehicle control demands much more than a sign, however. This paper proposes the development of a comprehensive space traffic control system (hereafter called SPATRACS) integrating sensor information (on- and off-board), providing collision avoidance information, and also deconflicting flight planning. It is possible to envision not only control of space assets, but with some of the advances put forth in the SPACECAST 2020 papers on surveillance and reconnaissance, a seamless and sophisticated aerospace traffic control system as well. This strategic vision includes a system meeting the needs of the twenty-first century and allowing the US to continue to pursue a competitive advantage in space (at least in this area). By consciously building on the US lead in this area, and by taking advantage of emerging technology, the US will fill a vital niche in the information high ground of space. With the ideas outlined in this paper, SPATRACS will provide future space traffic control while simultaneously increasing the efficiency of space operations. The paper will further show that, in addition to providing many opportunities for the future, many of the pieces of SPATRACS make sense on their own--now.

Fiscal pressures on current systems and infrastructure are already stretching the fabric of the US space establishment uncomfortably tight. This paper suggests that it is in just such an environment that the pursuit of a SPATRACS system makes sense. An active, focused effort is needed to fully realize the possible benefits through the fiscally efficient control and exploitation of space. This can happen with fundamental changes in the way the US military designs, builds, and operates (e.g., task, monitor, control) space systems to take advantage of new technologies and operational processes. A significant benefit will be the creation of a world where operations in and transit through space become more routine, realistic, and affordable.

The remainder of the paper will describe the primary elements of a new space traffic control concept. First, the paper will describe a framework for the future of military operations in space. Second, it will discuss the design changes needed to eliminate stovepiped[3] systems in favor of systems that can be unique yet conform to interface standards. Third will be a description of how space system design must change to support this philosophy, as well as the implications these design changes will have for space operations.

The key theme of each of these changes is increased satellite autonomy (to include on-board navigation and housekeeping functions), which implies the need to think about an entirely new way of tracking and controlling space systems (and those transiting space)--in other words, a space traffic control system. Many of the improvements proposed in this paper, when viewed in isolation, have the potential, on their own, for cost saving and increasing operational effectiveness. When combined, these proposals constitute a novel approach to space operations and a pivotal and dynamic space role for this country.

The Capability and Its Relevance

Historical Background

From 1958 to 1994, computers advanced from room-sized machines to hand-held personal digital assistants, fighter aircraft from the F-100 to the F-22, and arcade entertainment went from pinball machines to virtual reality. In the same period of time, however, US space operations made progress similar to the B-52--missions changed dramatically, technology charged ahead, but the same old shell, power plant and control systems remained in place. The B-52 remains an effective weapon system, and the US space operations system still performs adequately, however, both have outlived their design lifetimes.[4] The pace of innovation requires changes in military space operations--changes in approach, equipment, and manning. This paper advocates incorporation of technological advances merging the historically separate functions of satellite control and space surveillance into a much more capable and flexible scheme.

Assumptions

In the year 2020, an ever-increasing number of satellites will be orbiting the globe. Access to space is assumed to be much more affordable and responsive. Satellites will be smaller and last much longer than the satellites of today; while some might be deliberately designed for short life and early replacement to take advantage of continually emerging technology. Satellite missions will be more varied, but the underlying spacecraft capabilities will enable a more routine approach to space operations. Human involvement with each satellite will be greatly reduced and more closely resemble the

current air traffic control interaction with aircraft. The controlling function of this space environment will be the SPATRACS.

The space segment of SPATRACS itself will consist of a few (<20) small, simple satellites composed of passive sensors and on-board processing responsible for tracking all objects in space. The crowds in space and the need for comprehensive collision avoidance and satellite deconfliction will be compelling, and as a result, both civilian and military satellites will be designed to work interactively with SPATRACS.

What is Space Traffic?

To outline how this paper envisions the future, a more complete understanding of the environment will help bring the concept into focus. Three kinds of objects will exist that must be accurately tracked in order to accomplish true space traffic control: debris, uncooperative space systems, and SPATRACS-capable space systems. The debris problem is growing, and will likely increase in the coming decades. In SPATRACS, debris will be identified by space sensors and once identified, will be tracked easily due to its deterministic flight path degradation. With improvements in sensor technology, identification and tracking of increasingly smaller pieces of space debris will be possible.

The second category of space objects, uncooperative space systems, are non-interactive members of the SPATRACS family which include any pre-SPATRACS satellites still operating after system implementation. Since dumb satellites will maneuver without continuous on-board position reporting, they will require more SPATRACS asset allocation and attention. As with debris, space-based surveillance technology will provide track information of these objects. The number of objects requiring external sensing as the primary means of tracking will decrease as the SPATRACS standard on-board navigation and reporting systems are included in future space platforms.

The third category, SPATRACS-capable space systems (with transponder-like gear) provide constant, crosslinked position updates to the interlocked brain on board controlling satellites.[5] Satellites on orbit, as well as new launches in the twenty-first century, can and should be designed to effectively interface with SPATRACS. Every SPATRACS-capable system will carry internal navigation and housekeeping packages and perform (and report) routine station-keeping maneuvers on their own. Multiple

phenomenology sensing will allow the position and navigation systems to be updated (much like the way inertial navigation systems are "zeroed" at a known location). This affords more accurate telemetry and allows satellite tracking like aircraft in the current air traffic control system. Aircraft position is constantly tracked by transmitted (IFF) and external (radar) sensing, and analogous systems will apply in space. The satellite will report to the SPATRACS constellation and passive sensors will provide additional position checks.

The design and integration of SPATRACS capability into satellite design is critical if the system is to be adopted. User participation will grow as the system evolves and proves its worth. Early generation SPATRACS could perform the bulk of its mission using its own sensor information. Additionally, SPATRACS satellites should be designed to incorporate off-board information.[6] As satellites become increasingly autonomous, ever increasing accuracy can be realized.

Operations Under SPATRACS: Merger of Satellite Control and Surveillance

For the most part, sensors for this system will be space-based. Due to the elimination of atmospheric interference, these sensors will be able to detect and track very dim targets (visible magnitude 15 or 16 is possible).[7] Although they will mainly be passive sensors, given sufficient numbers and on-board processing and crosslinking of data, they will be able to generate accurate orbital elements for the objects being tracked.[8] Low to medium (spatial) resolution visible spectrum sensors will conduct the bulk of the space surveillance. These will be augmented by similar resolution IR sensors to track high priority targets in Earth's shadow, detect new launches, and track maneuvering targets. Space object identification will be conducted through one or more of the following methods: spectral signature analysis using low to medium (spatial, but high multi/hyper/ultra/omni-spectral) resolution sensors, deployment of higher spatial resolution sensors, or use of medium resolution sensors to produce interferometric images.

Having generated track files, tentative object identification and catalog updates on orbit, the system will then downlink the information to a central facility providing fusion with other data (e.g., from ground based sensors which are advantageous for gathering some types of data), validation, and additional analysis. In addition, the facility will develop tasking for the space surveillance network (which will have capacity for specific

observations beyond orbital catalog maintenance, e.g., to focus efforts in anticipation of the launch of a new threat country space asset). This facility will be directly linked to a main satellite control facility, so collision warnings will be immediately available for action, to customers interested in space object track data.

Relatively small crews (by today's standards) will man SPATRACS ground stations. These ground stations (primary and backup) will be responsible for handling anomalous situations, authorizing, coordinating and reporting collision avoidance maneuvers with satellite owners, and coordinating space object identification (particularly threat identification). Overseas ground sites, with their cost and vulnerability, will be eliminated. All the data gathered can be augmented by ground site data collected from continental US (CONUS) bases, but the system can remain autonomous.

The long-term integration of SPATRACS with all space satellites could be planned for later in the twenty-first century. The initial SPATRACS, as described above, could perform the bulk of its mission using its own sensor information. SPATRACS satellites should be designed to allow for the incorporation of off-board information available from other satellites as well. As other satellites become increasingly autonomous, increasing accuracy can be obtained from SPATRACS. Satellites after the year 2010 should all be designed to effectively interface with SPATRACS. More specific information about the technologies required by SPATRACS are in subsequent sections of this paper.

The SPATRACS system will have some degree of on-board intelligence, and won't depend entirely on any central facility. SPATRACS could, for example, automatically track and provide information on enemy space assets directly to a theater commander in chief (CINC). The degree of automation in the process and the location of human decision makers in the system are architectural issues that need to be addressed.

Atmospheric Traffic Control

When space travel or space transit (using a transatmospheric vehicle) becomes routine, a system like this is essential. A fully capable "aero" space traffic control system, (seamlessly integrated with the air traffic control system) will allow for conflict-free transit of multiple simultaneous events.

Advantages

If the US is able to provide a space traffic control system many advantages will be possible:

First, financial advantages abound. If the US adopts the proposed new vision for space operations, the savings over time will be considerable. Much of these savings will be realized through the elimination of stovepiping and over-reliance on manned ground systems. Selected information can be sold to commercial operators or foreign governments, helping pay for the acquisition and maintenance of a system in a time of declining budgets. It will need to be available at a price encouraging its use, and not so expensive to use that other nations will be tempted to develop their own system. A national, long-term strategy to underwrite entry into the business may be required to provide this kind of early, low cost service and will lead to substantial downstream savings.

Second, space operations will be streamlined. The significant US presence and influence in space will remain intact precisely because the nation moved quickly to a more consistent, efficient approach to space operations to insure competitive advantage. This vision sees space operations as more regular and affordable, expanding the bounds of what is doable from space. This philosophy implies basic changes in the way space systems are designed and built, provides for a more efficient and effective means of operating space systems, greatly increases US awareness of and ability to respond to changing situations in space, and ties all these things together under the umbrella of SPATRACS. Such changes make sense: even at the existing level of space operations, savings of hundreds of millions of dollars per year are possible.[9]

Third, such a system is a prerequisite for space control. If the US has a system that can provide current, accurate, and precise information on satellite position and movement, it then becomes feasible to deny that information to potential enemies--and use it for the nation's advantage. Such information is required for intelligence as well as for space control purposes in time of conflict. By possessing dominance in this area, the US might be able to deny potential adversaries many space control options. It also comprises a platform for developing space tracking and detection that will be a force multiplier in a future that might include space-to-space force employment.

Issues

Some potential problems will arise with a system like SPATRACS. Those problems include the international agreements that will have to be negotiated to allow this system to be world-wide in scope. Given a world where there are enough actors to make it feasible, aerospace traffic control becomes a security issue for satellite owners and a significant source of leverage for the controller. In the history of international agreements, where the subject of discussion is of relatively minor interest (e.g., the Antarctica Treaty), the agreement enjoys success. Once vital national interests come into play (like they will if space traffic control became vital to space use), there is both trouble achieving agreement and more trouble enforcing compliance. Another problem is that the US will in some sense become a space insurance agency, thereby potentially incurring liability. If a space operator is told that their planned or current track is debris-free, and they take a lethal or debilitating impact from space junk, is the US responsible? If it happens to an unfriendly (from a US point of view) international actor, did the US set them up for failure on purpose, and what will be the international implications of such an incident?

Also, a technical vulnerability issue of standard systems that must be addressed. There is the chance for introduction of a Trojan Horse that could disable all your systems, and since that chance exists, how should it be countered? Is there a requirement for multi-level security when you have certain users that only need certain information? None of these are easy questions, but they do not detract from the general desirability of the SPATRACS concept, and some (e.g., multi-level security) are already being worked.

Space Operations: Design and Philosophy

A truly effective military space capability must be responsive, resilient, flexible and cost-effective. Perhaps one of the greatest leaps needed to reach the SPATRACS vision is a change both in the design of space systems and the philosophy of operating them. Current stovepiped, manpower-intensive systems have none of these characteristics and look increasingly anachronistic under the budgetary heat lamp. This paper will identify additional actions sharpening the aim toward a more efficient mode of space operations synergistic with this concept of aerospace traffic control.

The operator of every satellite system, be they military or civil/commercial, defines the interfaces that satellite designers must satisfy to support ground operations. Ground operations themselves are defined by satellite owners. Historically, there has been very little commonality in any of these areas. The result is a series of stovepiped satellite operations where no two systems are exactly alike. An operator trained to support one satellite system must be retrained before crossing over to another system. The development of better standards for space operations will eliminate these inefficiencies and will create savings in satellite operations and development.

Interfaces

Interfaces concerning satellite navigation, housekeeping, and telemetry, tracking, and control (TT&C) must be defined (see "Standardized Space Systems Design" below). This effort should take its cue from the computer world and focus on enabling an open system architecture based on standardized protocols or languages rather than inflexible, mandatory hardware and software standards. Since interfaces have to be defined for system designers anyway, and if intelligent standardization is recognized as a goal that will result in significant savings, standard interfaces should be defined supporting space traffic control. Satellite design requirements must include on-board processing to accomplish many of these functions currently performed on the ground.[10] Such standard interfaces (hardware, software, data, etc.) will be phased in as technology, particularly improved on-board processing, becomes available. An aggressive technology program should be pursued while a joint working group of civil/commercial/military satellite operators work at the development of a roadmap to implement standards for integrated operations. As these standards are worked out, the next logical step is to begin to apply them in practice, namely in improving standardization in the design of new space systems.

Several concerns with this approach must be addressed. First, haphazard application of standards can drive up costs and reduce flexibility, exactly opposite the desired effect. Second, implementation of common systems must always guard against vulnerabilities (e.g., if only one common set of code controls all satellites, every one of the satellites is vulnerable to an error in the code or to software sabotage). Third, for the foreseeable future, space systems will continue to include highly classified payloads, so any system of interfaces must address the need for multi-level security capability. None

of these are show-stoppers; in fact, they are problems that are being dealt with for command and control and for other systems already, but they must be addressed.

Space System Design

What design elements must change to prepare for space operations in the next century? Virtually all aspects of space system design need to be addressed, including: interfaces, launch concepts, orbital insertion and checkout, spacecraft "housekeeping", navigation, telemetry, tracking and control, mission payload management, space system ground segments.

How should the US redesign space systems to provide more effective traffic control, and what effect will this have? The first element of the redesign is to get away from detailed system design specifications and concentrate on interface specifications. This means not only the on-board hardware interfaces (physical, electrical, thermal), but even more critically on the data interfaces for the payload to communications system, inputs and outputs for spacecraft housekeeping, navigation and control functions, and ground segment hardware. This idea specifically addresses the problem of stovepiped systems--rather than a unique design of everything from the launch vehicle interface to the mission data ground workstation. A focus on interface specification allows an increased degree of commonality among space systems, both in hardware and software, and has the potential to greatly reduce training and operations costs. This interface requirement is analogous to the personal computer video bus standard (e.g., VESA), which enormously improves system integration, but allows for competing systems to forge their way to market when other system capabilities outpace bus limitations. The key is to develop standards that do not overly restrict innovation and still allow upgrade to new integration standards when technology drives expanded capabilities.

For launch systems, an improved space operations concept requires that payloads be less complex and fragile, and less dependent on specific expertise. Given an inexpensive, rapid, flexible, and reliable way to get to space,[11] payloads can be designed either to fit whatever volume is available, or to be assembled on orbit from segments fitting the launcher envelope. Again, interfaces from the satellite to the launch platform should be standardized so that whatever on-orbit capability is required can be launched on demand.

Satellite designers should take full advantage of miniaturization, modularity, and standardization to design systems that can be rapidly upgraded or tailored to a particular mission and delivered for launch with minimal test and check-out. Where on-orbit

upgrading is desirable, maximum use should be made of designs allowing software upgrading to improve performance (there are lessons to be learned from NASA's deep-space probes in this area). Design philosophies must emphasize rapid, flexible design and manufacturing of satellites, even if they come at the expense of satellite endurance. Given the right launch system, it is economically and militarily preferable to possess surge capability with *competent* spacecraft than to orbit a few exquisitely capable but irreplaceable battlestars.

Moving to the area of on-orbit operations, spacecraft must be designed to allow more rapid check-out and activation. It does no good to put a satellite on orbit within hours of a request if it takes weeks or months to make it fully operational.[12] Modularity, standardization of interfaces, and a reduction in complexity of individual satellites will help reach the doctrinal design goal. There is the possibility of on-orbit servicing and design for upgrading or tailoring.[13]

Once a spacecraft is operational, an inordinate amount of manpower and contact time is currently devoted to routine functions such as housekeeping and navigation. Today's satellite control system is archaic and should be replaced with a three-tiered approach: 1) On-board systems will perform routine housekeeping and navigation chores (this is well within current technology) and update the ground segment periodically. These on-board systems will have sufficient intelligence to alert ground operators if any parameter was diverging unacceptably from nominal values. 2) The second tier will be an austere ground segment with a standardized human-machine interface and expert system support to handle most likely satellite emergencies. 3) Finally, there will be an available technical troubleshooting staff if a problem requires expertise beyond that built into expert systems (this staff will constantly update the expert systems too.) The work of these troubleshooters will be diminished significantly by the increased commonality in space system design. One group conceivably could perform depot-like support for all space systems, whereas costly technical staffs currently are employed for each individual system. This environment will greatly reduce training requirements, and as a result, smaller numbers of spacecraft operators will qualify more rapidly, move from system to system with minimal difficulty, and handle surge requirements during expanded and crisis operations.

With spacecraft functions and interfaces standardized, the only specialization among satellite systems will be in mission payloads. Here also, interface specification and careful satellite design will reduce or even eliminate differences in routine operations among systems. In terms of the ground segment, only the mission element (tasking system, data displays, and analytical support) will be different from system to system, and this element need not be collocated with the spacecraft control element. This will allow mission terminals (of relatively small size and weight) to be deployed in support of theater or other warfighters, while the routine operations functions are kept separate and at the most convenient location.

The above improvements will greatly reduce the need for many current satellite control practices. Satellites will be able to handle many functions on their own; for example, knowing their own position, monitoring their own health and status, discharging and recharging batteries as necessary (perhaps even performing some self-repair), and carrying out theater CINC mission tasking autonomously (i.e., the mission payload ground segment will task a satellite to perform certain functions--with the aid of software to ensure these functions are possible--and the satellite will carry them out on its own, pointing, tracking, and perhaps even maneuvering as necessary). A control site will monitor regular reports from the satellite, allocate priorities to various users of the system (e.g., for multi-theater support) and intervene in an emergency. This does not imply a single geographic location (which might become a critical node) for all space system control. Functions can be redundant or physically dispersed, yet linked electronically. The key is that the space segment will be far less dependent on <u>any</u> ground support than current systems. Under normal conditions, the system will require little direct control. Power, weight, bandwidth, and ground segment assets currently used for TT&C could be allocated to more mission oriented tasks.

The combination of technologies, design practices and procedures mentioned above will have the effect of reducing the frequency and duration of contacts a satellite (or an entire constellation) must make with the ground.[14] This will not only reduce the number of personnel required, but will greatly reduce space system vulnerability through decreased dependence on ground sites, to include elimination of overseas ground sites via data crosslinking. Not only is the system less vulnerable because the ground sites are removed as targets, but spacecraft are less dependent on ground contact in general, and can operate autonomously if there is a communications outage, destruction or degradation

of Consolidated Space Test Center (CSTC) or Consolidated Space Operations Center (CSOC), or other conceivable degraded conditions.

A further step needed to operationalize space is improvement of space surveillance, tracking and identification (SSTI) capabilities. Since the spacecraft described above will be more autonomous, the concept of a SPATRACS gains validity and more closely approximates air traffic control. Eventually, the two systems could even overlap and merge when true aerospace vehicles come on line.

Future Evolution of SPATRACS

Spaceways

As an interim step to full satellite autonomy, "spaceways" may have to be created. Like today's airways or jet routes for domestic and international aviation traffic, which fulfill the need for traffic deconfliction and sequencing as a means of ensuring safe air operations, tomorrow's spaceways could fulfill similar functions. The determining factors will be: (a) the actual risks of collision; (b) the degree of legal, financial or political liability should collisions occur; and, (c) the degree of international cooperation on the issue of safe operations in space. If there is high risk of collision, clear liability and heavy, enforceable restitution, and increased international cooperation regarding travel through the region of near-earth space, spaceways could provide an interim solution.

Spaceways, like airways or jet routes, have a set of minimum requirements. There are at least five of these. First, there must be an authoritative definition of what constitutes a route. On the earth, these are straight lines between two fixed terrestrial points. Since the earth rotates beneath orbiting spacecraft, the definition of spaceways would be more complicated. Second, traffic on the route must remain on or within whatever defines the route, and both the spacecraft and the controlling agency must have some way of knowing this. Aviation operations in Positive Control Airspace (PCA), for example, require both a two-way radio for instructions and position reporting and a transponder which electronically indicates aircraft position and, in most cases, altitude. Third, there must be some kind of controlling agency responsible for route assignment and route monitoring. Fourth, re-routing or off-route operations must either

be sanctioned by the controlling agency as "conflict-free" or the maneuvering spacecraft (and its owning controlling agency) must accept that the spacecraft is moving with "due regard" (in the case of military air operations today, some are authorized only after the military declares "MARSA," or "Military Assumes Responsibility for the Separation of Aircraft) for other potentially conflicting traffic. Fifth, there must some kind of penalty or sanction should a collision occur. Each of these minimum requirements deserves elaboration.

Orbital positions are defined by an element set. Once established in orbit, and unless it is maneuverable, the spacecraft will remain in that orbit. For very low orbiting spacecraft, atmospheric drag and the force of gravity have the effect of decreasing the spacecraft's height above the planet over time. A spaceway, then, would be defined by the satellite ephemeris or element set once established in orbit. Three-dimensional separation requirements would define the spaceway.

Some nations have very sophisticated spacecraft and multiple means of space surveillance and space object identification and tracking--radar, optical, and others. Other nations rely on interferometer or radio, only able to confirm where their spacecraft actually is during part of its orbit. If there are to be spaceways, all spacefaring nations or non-state groups need to know that their spacecraft is on the spaceway. If they lack the indigenous capability of knowing this, they must acquire the information from somewhere and it must be accurate. The United States, today through the United States Space Command and its Air Force Component, has superior space surveillance capability compared with other nations. Spaceways, then, cannot be created without the active cooperation of the United States.

Depending on the degree of international cooperation in space, an entity of or in the United States might become the foundation for the controlling agency. It is arguable on the one hand that the other users would accept United States' control, or that on the other hand the United States would relinquish the control it presently has. It is not inconceivable, however, that at some point the United Nations might become the controlling agency for spaceways subscribed to by spacefaring nations. Services provided by other nations would be provided for some sort of compensation. Since an agreed-upon controlling agency is one of the minimum requirements for spaceways, absent such an agency deconfliction will be done at the election of the user. Unless there is a controlling agency, off-route or maneuvering operations in space will all be like

MARSA is today. The same nations that have the most sophisticated surveillance capability would logically have the most sophisticated spacecraft, including manned spacecraft and trans-atmospheric vehicles. Obviously, these would not be moved or maneuvered without assessing the risk of collision.

Should collisions occur, liability would have to be fixed and some type of penalty assessed. These provisions already exist. The problem with having a controlling agency, is that the agency itself could be liable for causing a collision. An international entity like the United Nations would probably be as unwilling to waive immunity as a national entity would be. All things considered, it appears clear that spaceways are no more than an interim solution. The goal must remain to have the highest value spacecraft the most able to avoid collision with other space objects autonomously.

Aerospace Traffic Control

Space operators in the future could enter a flight plan and automatically receive preliminary deconflicted clearance. In addition, ongoing, in-flight deconfliction will also be available without operator manipulation. It could integrate information from even more sophisticated sensors of the future, such as electro-magnetic, chemical, visible, and omni-spectral. Hand-offs from one sector to another will occur, but only in the on-orbit SPATRACS brain, which is transparent to the operator. This is envisioned as a next generation, smart system integrating volumes of data into information in a format giving the operators what they need to know on a timely basis.

Integration of atmospheric flight with SPATRACS will be a natural outgrowth when the learning curve with space operations merges with advanced sensor systems and transatmospheric flight. Even though much of the technology exists today for making space traffic control more robust and cost-effective, integrating air traffic control, to include flight planning, conflict avoidance, and sensing of anything transiting the air is far off, but well within a conceivable evolutionary chain. The computing and information handling ability required to take inputs from the wide variety of sensors and make accurate decisions increases dramatically when atmospheric flight is introduced. When that computational capability exists, air traffic control could be enhanced by fusing sensors and data to comprise a whole new way of doing business. As an example, a post-2020 air vehicle will have a navigation system which files and checks the flight plan,

offers fuel saving tracks (through integration of weather and jet stream data), provides constant in-flight collision avoidance, and stacks it into busy airports automatically. Transcontinental, oceanic, global flight will be free of air sector hand-offs because the transitions will occur in the brains of SPATRACS and will be transparent to the operator. This vision for seamless, total air and space awareness is a natural stepping stone to more brilliant sensors and information synthesis as envisioned in the white paper on "Surveillance and Reconnaissance in 2020."

Of course, there are significant differences between air and space traffic, and potential aerospace vehicles will further complicate the picture. Some of those differences are summarized in table 1. This figure illustrates some of the factors requiring a change from current air traffic control and space control systems and procedures to accommodate true aerospace vehicles.

	Air	**Space**	**Aerospace**
Flight Path	Variable	Mainly deterministic	Mixed (dep. on phase of flight)
Speed	100s kph	~10,000 kph	From air to space speeds
Control Type	Hand on stick	Machine	Both
On-board system management	Fully autonomous	Little autonomy (now)	A mix
Comm Method	Voice	Telemetry	A mix
Nav inputs	INS, GPS, altimeters, etc.	INS, GPS? star/horizon trackers, ground	All
Maneuvers	Unpredictable	Constrained	Both

Table 1. Differences in Air and Space Traffic

Planetary Warning

SPATRACS will also be a logical tool for a planetary warning system (described in the white paper Preparing for Planetary Defense) tying together Earth, Moon and other space-based deep space sensors to detect potentially dangerous Earth-orbit crossing objects sufficiently early to take action. If it can accurately track and fuse satellites at great distances, focusing and tracking other space objects will not be a great leap.

Summary of the Capability and Its Relevance

An integrated effort to create a new methodology for designing and operating satellites will clearly have a high payoff. If such an effort is pursued, it is feasible that by the year 2020, all on-orbit systems could be integrated and controlled by a SPATRACS that will significantly improve US operational military capability, and yield tremendous savings in space system design and development costs.

SPATRACS is more than an interesting mission in space. It defines a future for US space operations in line with the nation's traditional aerospace leadership role and avoids a quagmire where institutional inertia cannot be overcome. The benefits that could be derived through the focused integration of doctrine, policy, and operational systems is nearly limitless--and should be pursued. Having outlined the basic thrust of SPATRACS, this paper now zooms in on a more in-depth discussion of required technologies and programs.

Potential Technologies

This section will describe a roadmap for integrating near-term and far-term efforts and changes in technologies and doctrine necessary to fully meet the vision of space operations in 2020 described in this paper. The next section (Near-term Technologies and Operational Exploitation Opportunities) will reiterate some of the critical near term activities recommended for immediate action or continuation. Overlap between these two sections is intended.

Most of the component technologies needed for implementing the new space operations, monitoring, and traffic control architecture described above are either already available or are rapidly emerging. This does not mean that the sum of the parts is either

obvious or easily implemented; however, test and demonstration at the system level is absolutely essential. Practically speaking, wholesale changes cannot and will not happen overnight. Risk aversion, institutional inertia, presently programmed acquisitions, and funding limitations will encourage a gradual pace of change. In the near term, measures to prove key technologies in operationally realistic environments, reduce system-level risks, and demonstrate operational and cost advantages are necessary. All of these, in aggregate, will sow the seeds for future generations of space systems that achieve the vision described above.

Direction

To some extent, the long lead indicators of change are present in documents such as US Space Command's "Space Logistics Master Plan"[15] and "Sustaining Space Systems for Strategic and Theater Operations."[16] Senior military space leaders are calling for new satellite systems to incorporate modularity, standardized interfaces, and ground segments requiring less manpower. There is general recognition of the need for more flexible, responsive and cost-effective operations. This paper recommends the military services turn the attention of their space doctrinal development organizations to assessing the impact of emerging technologies as described herein, with the goal of building a joint doctrine driving coordinated space system development instead of merely adapting to the limits of current systems.

Technologies

<u>Space-Based Space Surveillance</u>

Sensors/detectors. For the most part, detector technology is sufficiently advanced to build the kind of capability required for satisfactory identification of space objects. It is fully expected, that by the year 2020, sensor technology will be advanced far beyond the requirements for the system described in this paper, to include the first glimmers of next-generation atmospheric transit sensors.

Optics. Light weight and thermal compatibility (with detectors and host satellites) are the primary features needed here. New approaches, like silicon carbide optical elements, may be preferable to traditional multi-metal telescope designs. The Phillips

Lab Space Surveillance, Tracking and Autonomous Repositioning (SSTAR) experiment has proposed demonstrating such a device.

Position determination. A space-based system must be able to accurately determine its own and the track's position. Current position can be gained from global positioning system (GPS) or other autonomous navigation techniques, while accurate determination of the track's position will require correlation of data from more than one passive sensor (a single passive sensor suffers from an inability to get unambiguous range data, even against fairly deterministic tracks such as satellites).

Brains/software. New algorithms and data handling routines will be needed to incorporate space-based data into the space surveillance system (which is ground-based today). Some of this work has already been done for the Space-Based Visible (SBV) experiment on board the ballistic missile defense office MSX satellite.

Deployment. The sensor/position determination/brains/communications package can be deployed on light, dedicated satellites, and probably can also be deployed as a piggyback package on satellites with other primary missions. A modular design will greatly aid in this, as the SPATRACS system could easily be distributed on the host.

Tasking and analysis/ground segment capabilities and requirements. These should be developed in conjunction with the demonstration of space-based space surveillance hardware and software. This will take full advantage of new capabilities and maintain parity with advances in other space systems in the areas of flexibility, modularity, reduced manning requirements, etc.

System-level demonstration. This is vital to the acceptance of the space-based space surveillance concept. SBV will be a first step in this direction. The SSTAR demonstration will be significantly more comprehensive and allow for true operational utility demonstrations.

Launch Systems

Reducing launch costs and making access to space more reliable and flexible is essential to any efforts at improving space operations. The SPACECAST 2020 white paper on spacelift addresses this problem in more detail.

Autonomous Navigation

GPS receivers that can provide navigational inputs for spacecraft are currently available. One is being flown on the Technology for Autonomous Operational Survivability (TAOS) experimental spacecraft launched recently. TAOS also incorporates on-board sensors and a flight computer providing a truly autonomous (as opposed to a GPS-based system, which naturally depends on GPS signals) navigation capability. TAOS incorporates other features desirable for autonomous operations, including a new electronic architecture with the first use of a MIL-STD 1553B data bus connecting the various subsystems. Perhaps most importantly, its planned experiments will provide the first chance for space system operators to become familiar with a satellite with some autonomous capability. Many other experimental satellite proposals in recent years included autonomous navigation capabilities, but most of these foundered for lack of money. The next key step is to tie autonomous navigation to other elements of autonomy, such as housekeeping, on-board mission data processing, expert systems in both the space and ground segments, and to put these together with mission-oriented experiments (e.g., surveillance) to convincingly demonstrate the positive cost and operational impacts to warfighting CINCs and space system operators. The SSTAR demonstration incorporates several of these elements with a space-based space surveillance mission payload.

A further goal of SSTAR is to show that elements of the modular system can be attached to any satellite with minimal impact. The following elements are demonstrated on SSTAR: space object tracking optics and detectors that can double as high-precision star trackers for attitude determination, an autonomous position determination system including a GPS receiver, and a communications package. In other words, these modular capabilities will not only make a space-based space observation platform out of any satellite, but will also give that satellite a precise autonomous navigation and attitude determination capability.

Standardization and Interfaces

TAOS is also an important first step in this area, with its Space Test Experiments Platform (STEP) spacecraft bus and the 1553B data bus. A more significant program, since it addresses on-board interface standardization and the ability to design spacecraft modularity to a greater extent than STEP can, is the ARPA-sponsored Advanced Technology Standard Satellite Bus (ATSSB) program, which has suffered from funding cutbacks. Although the contractor proposals received for this system indicate a high degree of confidence that they can design and build multi-mission, modular spacecraft buses, a full-up demonstration is almost certainly an essential risk-reduction element before the government specifies features for operational satellite systems.

Modularity

TAOS and ATSSB both incorporate key elements in proving the concept of modularity; the next step is to prove the flexibility of the basic spacecraft design by flying different missions using the same platform. In addition, there are few technological obstacles to design a satellite for remote (as opposed to human, which has already been proven with the Hubble space telescope) on-orbit servicing, repair, and upgrading. The key obstacles are the cost of getting to orbit combined with the penalties of designing a system for servicing. In the past, this made servicing unattractive compared to replacement. With new technologies available, however, it is worth revisiting this concept as a hedge against increasingly expensive large booster costs or to take advantage in a breakthrough that dramatically lowers launch costs for small payloads. An application of modularity will be the design of systems for assembly on orbit.

Expert Systems

There appears to be no great obstacle to concurrent design of an on-board, rule-based expert system for a spacecraft incorporating the design techniques mentioned above. For experimental (initially) and operational (later) purposes, the satellite will have sufficient on-board processing power, memory and a suitable operating system to execute such software, then the expert system can be developed over time from ground operations and regularly updated and uploaded to the spacecraft. This system will eventually take over routine housekeeping functions, subsequently expand its capabilities to deal with minor anomalies, and perhaps (again assuming appropriate satellite design) progress to

managing emergency situations (non-fatal impact, subsystem failure) and perform self-repair (e.g., by reconfiguring subsystems to compensate for some kind of failure). The design can be sufficiently flexible to allow for gradual testing and implementation as the expert system gets smarter and the human operators gain confidence.

Operating System Software

There currently is no software operating system (analogous to DOS for personal computers) for spacecraft. Each military space system is custom designed and coded, with corresponding extra cost and incompatibility. This paper strongly supports initiatives such as Phillips Lab's Reusable Operating System Software (ROSS) that will attempt to correct this deficiency.

Electronics

The primary elements for this new space operations concept are sufficiently powerful (but not power-hungry) processors and on-board memory. A thorough study of processor design choices is needed. Should the US continue with customized MIL SPEC designs such as the Advanced Spaceborne Computer Module (ASCM) which, though offering impressive radiation hardness and other design capabilities, is already generationally obsolete, or can the military now accept some system design compromises (shielding, redundancy) to make use of the latest commercial technology in satellite design? For on-board storage, pursuit of solid-state memory devices to replace tape recorders as standard mass storage on board spacecraft is necessary.

Communications

Independence of satellite constellation to ground stations and improved space surveillance capability depend on high capacity, secure crosslinks. Laser crosslinks are preferable to radio frequency systems because of size and weight considerations,. Although the laser crosslink program for the Defense Support Program (DSP) system has a checkered history, alternative approaches (such as Phillips Lab/MIT Lincoln Lab's LITE program) may be ready to provide the required capability. Up and down link requirements will be reduced by performing more routine functions in space (e.g., it will be simpler to downlink orbital elements from the space-based space surveillance system

than to dump all the raw observation data to the ground), but this will require confidence building demonstrations before it can become widely used.

Ground Segment

In parallel with satellite design and development, the ground segment must be completely restructured. There is no technical reason why a satellite or even a constellation incorporating a degree of autonomy cannot be controlled by a very small number of personnel using software-reconfigurable workstations.[17] As with most of the other issues, this is not as much a matter of new technology as it is of smart design and a change in operational philosophy. Particularly, this requires separating satellite and constellation control functions from payload tasking and mission data receipt, analysis, and dissemination. With suitable demonstrations and testing, the concept of a warfighting CINC's staff directly tasking and receiving data from a mission payload without compromising centralized control of the satellite itself could be realized.

Near Term Technologies and Operational Exploitation Opportunities (Including Commercial Opportunities)

The following paragraphs comprise a list of existing initiatives pointing toward the new system architectures required by SPATRACS.

The TAOS experimental spacecraft is essential for demonstrating many of the critical technologies needed to fulfill the vision described above. Its planned experiments will provide the first chance for space system operators to become familiar with a satellite with some autonomous capability.

Even though the ARPA-sponsored ATSSB program has been suffering from funding cutbacks, such a system is essential to meeting the desire for standard satellite modules in the future. If the ATSSB is not pursued, another effort will need to take its place. The commercial sector (e.g., Motorola's IRIDIUM) is also pursuing standard buses. A joint government and commercial effort could be beneficial in this area.

Phillips Laboratory's ROSS is an important critical program that should be continued. It is also a program that could be worked jointly with commercial industry. Bill Gates, founder of Microsoft and father of DOS, recently announced plans to build an

840 communication satellite constellation. If DOS and Windows are any indication, he will clearly be developing a standard operating system. Joining forces early could be a tremendous advantage.

Laser crosslink is an essential capability that is not being aggressively pursued. Increased efforts are recommended in this area. This will free SPATRACS compatible satellites from RF spectrum squabbles (a major problem) and provide information control.

In the BMDO programs, the SBV experiment is an important demonstration of many critical technologies. Continued support of SBV is recommended.

Also, the Air Force's Brilliant Eyes program implements many of the same concepts this paper proposes. This paper does not compare specific technical merits of one program to others (e.g., DSP), but recognizes that some of the elements of Brilliant Eyes pertain directly to the kind of satellite that will likely be developed in the next century (smaller, more autonomous).

In the commercial sector, the development of expert systems along with powerful computer processors with large on-board memory is an area in which the government will have continuing interest. Yet, it is in precisely these areas where the commercial sector is proceeding faster. Therefore, the government should closely monitor the commercial sector and take advantage of their efforts. Large government programs are not required, but a significant commitment to developing effective interfaces (people to people) is in the government's best interests to ensure that any military-unique requirements are adequately addressed. The SPACECAST 2020 white papers on "Global View: An Integrated Joint Warfighters Command, Control, Communications, and Intelligence Systems Architecture" and "Surveillance and Reconnaissance in 2020" go into greater detail in this vital area.

Conclusion

SPATRACS--a design for space traffic control--is also a vision for the future of the US space operations. Risks to both new and existing space assets are increasing, and within the answer to that problem lies improved opportunities for operational effectiveness across the board. The creation of an integrated space traffic control system

will head off serious problems that result from space tracks becoming increasingly conflicted. If the system goes beyond space-based sensors and becomes a part of satellite design, deconfliction could be highly accurate and would improve the usability of space. By freeing up spaceways, it would provide enormous benefits not only for the military, but for the civil and commercial space sectors as well. The systems proposed in this paper each have value on their own merits and, when combined in SPATRACS, result in many and compelling benefits.

In the years following World War I, US aviators' ability to see the air dimension as much more than a land support arm paved the way for a legacy of air superiority that this nation enjoys today--but only after a great deal of effort was focused on gaining the support of senior military and political leaders. That same opportunity exists today in space, and this paper brings the vision into sharper focus by laying out the path to US space domination in the next century.

NOTES

[1] Nye, Joseph P., Jr., Perry, William J. Schear, James A., Scowcroft, Brent, and others. Seeking Stability in Space. Aspen Strategy Group and University Press of America: 1985. p. 4 and p. 26.
[2] Horner, Charles A. Testimony to the Senate Armed Services Committee, 22 Apr 93.
[3] Stovepiped, as used here and elsewhere in this paper, refers to the tendency for all military space systems to develop on their own, without interfacing with other satellite systems--much like a pipe on an old stove that would do its job in total isolation from the other pipes.
[4] In some ways, this analogy is even deeper than it appears. Like many of our space systems, the B-52 was initially over-designed. As a result, each has been upgraded and used for missions never originally intended. Perhaps, in a way, each was too good initially and thus inhibited development of even more effective (and more efficient) follow-on systems.
[5] The brain is contained on the 20 SPATRACS system satellites. SPATRACS-capable satellites will be crosslinked to the 20 satellite brain. In sum, the system contains 20 controlling satellites and is supported by information from other satellites that can communicate with them.
[6] To clarify, the sensors would be able to handle the entire load without incorporation of sensors located elsewhere. For instance, a ground-based radar could uplink to the controlling satellites and the on-board brain would incorporate the information into the tracking algorithm.
[7] Based on MIT Lincoln Laboratory Space Based Visible (SBV) experiment studies.
[8] This can be done with passive sensors using stereo viewing, similar to missile tracking. Augmentation with active sensors is an option.
[9] For example, Space and Missile Systems Center (SMC) studies showed replacing GEODDS with a space-based system could save $300M per year. This would be just a small part of the cost-saving changes envisioned by this paper.
[10] This was once a major limitation: the size, weight, power requirements and limited capability of microprocessors seldom justified their inclusion on board spacecraft, hence our historical emphasis on ground control. This changed with the emergence of ever-more capable electronics. Shorter satellite acquisition and deployment times (as well as deliberately shorter design lifetimes) would make the argument that "it's always easier to upgrade the ground segment" irrelevant.
[11] See SPACECAST 2020 White Paper "Spacelift Suborbital, Earth to Orbit, and On Orbit," June 1994.
[12] MILSTAR, admittedly an extreme example, will require about a year to complete its initial check out. (Space News report - 1 week after launch).
[13] See SPACECAST 2020 White Paper "Space Modular Systems", June 1994
[14] The cost of a contact can be as high as $10,000 per minute, depending on the system. (Conversations regarding SSTAR at Phillips Lab, April 1994.)
[15] Space Logistics Master Plan, HQ USSPACECOM, J4-J6 Directorate, DRAFT, April 1994.
[16] Sustaining Space Systems for Strategic and Theater Operations, USSPACECOM/J4L, 17 Sep 93.
[17] For cost reasons, universities in Europe used this approach for the small research satellites. Phillips Laboratory is using the same principles for its "Payload Operations Center." (Discussions with Phillips Laboratory Space Experiments personnel, 1992-1993)

21ST CENTURY WEATHER SUPPORT ARCHITECTURE

Overview

The twenty-first century battle area will be a highly lethal, cyberwar-oriented, four-dimensional regime with the dimension of time being the most critical.[1] To succeed, the warfighter must have immediate access to key information to make quick and accurate decisions faster than the enemy's OODA (observe, orient, decide, act) loop capability.[2] In a similar manner, the civilian and commercial world will be a fast-paced, computer-oriented regime where successful and profitable operations will be dependent on time sensitive decisions based on vast amounts of information.[3] One critical set of information, required by both the warfighter and the commercial/civilian world operators, is weather conditions affecting the mission to be accomplished. The weather information user, whether on the ground, at sea, or in the air, will need near instantaneous global access to worldwide weather information for a given point, a path, or an area in time and space anywhere in the world. This weather information must be accurate, universally available in a timely manner, packaged so it is easily usable by people who may or may not be weather-trained, and easily incorporated into software applications.

This paper proposes the development and operational employment of integrated weather information data bases, available to the weather information user at various on- and off-ramps of the information superhighway to meet the near instantaneous access, worldwide weather information needs of the twenty-first century.[4] Access to the weather information data bases will be obtained through interactive ports connected to the information superhighway via hardwire (fiber optic cables, coaxial cables, home and office telephone line connections), microwave or direct satellite transmission or broadcast.[5] Interactive ports will include such devices as large mainframe computer connections, small personal computers, or hand-held or vehicle-mounted (cockpit; tank; ship; ground) micro-processor receivers, capable of receiving direct satellite broadcast from the information superhighway.[6] The ultimate goal is for the weather information user to quickly obtain the information desired, anywhere in the world, through a push of a button or a flip of a switch, with or without hard-line connection or weather expertise.

Elements of the Architecture

The proposed integrated weather information data bases will consist of observational weather data, forecast products, climatological information, and weather advisories and warning information. Following are examples of possible data bases that can be made available to the weather information user via the information superhighway: [7] (1) current single station and gridded surface/upper level worldwide weather observational data; (2) global cloud imagery and cloud amount fields to include tops and bases of cloud layers; (3) area specific doppler radar and lightning strike information; (4) worldwide radiowave frequency propagation forecasts; (5) area specific environmental surface (ground, sea state) conditions; (6) single point forecasts and warnings for critical points of interest worldwide; (7) point or gridded worldwide climatology information; (8) globally gridded forecast fields of various weather parameters for specified time periods, both at the surface and specified upper levels; (9) hazard forecasts for icing, turbulence, volcanic ash, and fallout winds; and (10) gridded observed and forecaster wind fields at various levels.[8] The data bases can also consist of pre-tailored products, such as weather maps, graphic displays of data, plain language discussions, or specially processed data for use in special weather application software.

The weather information user will have several options in using the data. At the macro-scale level, forecast centers can use the information superhighway to acquire observational data from data processing centers, produce the forecast products, and then send the products back out to customers. The smaller scale user can directly order and obtain tailored products from a forecast or data processing center located at one of the information superhighway on- and off-ramps. The user can also gain access to weather information data base(s) residing at various information superhighway ramps, obtain the desired data, and generate his or her own weather products using on-site user software. For the warfighters, hand-held, vehicle or cockpit-mounted direct broadcast receiving devices could take the weather information directly from the information superhighway, insert it into microprocessors with pre-programmed decision aids, and within seconds, obtain a determination of weather impacts for a proposed mission.[9] Information provided from the microprocessor can be the actual weather data, to include direct broadcast of cloud imagery[10] and vertical sounding data, or a tailored product for direct input into a course of action decision process. The devices can also be designed to have a direct send/receive satellite transmission capability.[11] This attribute will enable the warfighter to obtain specific weather information via direct query access to the information

superhighway. The warfighter will also be able to insert current weather observations, for example, back onto the superhighway via direct transmission (figure 1). Civilian and commercial applications will be similar; possible users would include truck drivers, commercial airlines, farmers, local TV, universities, and radio stations, and private car owners.

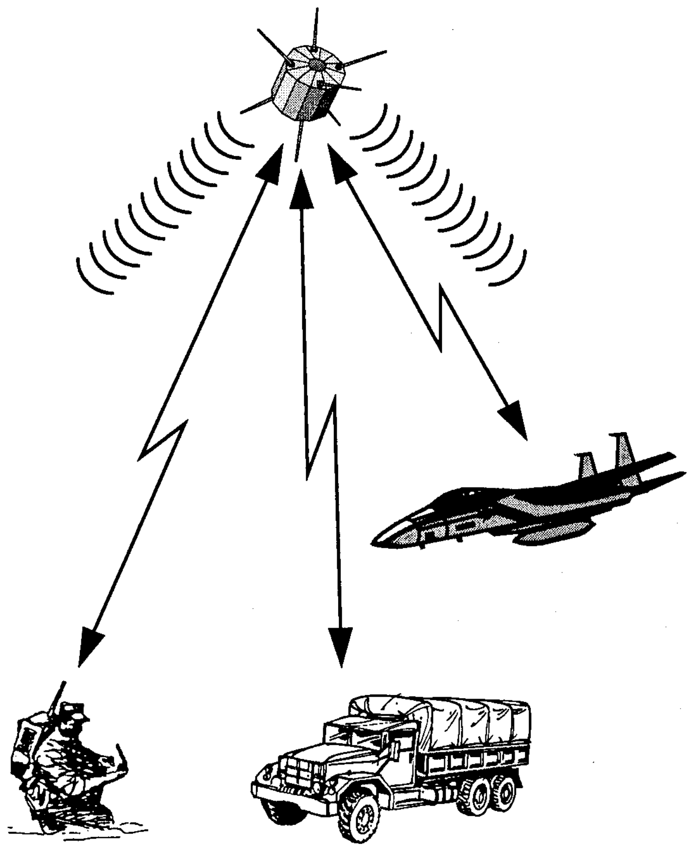

Figure 1. Near instantaneous, global access to worldwide weather data residing on the information superhighway for a given point, a path, or an area in time and space anywhere in the world. Direct access via satellite broadcast or direct send/receive satellite link.

The development of this proposed capability requires modifications and operational paradigm changes to four main aspects of the current national (Department of Defense) and civilian weather support system architecture: (1) data collection; (2) data base fusion and dissemination; (3) analysis and forecast product development; and (4) weather product and information dissemination. The extensive cost of developing new capabilities and of changing current operational weather support paradigms is expected to require a consolidated, joint-use effort among DoD, commercial, and civilian weather information producers.

Critical to the success of this proposal is the capability of our nation to continuously obtain, process, and disseminate vast amounts of worldwide, ground and satellite-based weather observations, both in war and in peacetime. Current temporal and spatial levels of observational collection will not meet the military or civilian weather information needs in the years 2020 and beyond. Every effort must be taken to expand, not decrease, our nation's weather observational capability, especially from space-based systems.[12]

The Capability and Its Relevance

Many of the pieces of the proposed capability exist in the world today or at least are on the drawing board, especially in the commercial sector, but are not woven together to produce a streamlined operational architecture providing civilian or military users near instantaneous access to worldwide weather information data bases from any location in the world in an easy, economical, or efficient manner. Development of the information superhighway and its on- and off-ramps, availability of interactive port hardware and software, computer processing capability, data availability bureaucratic barriers, budget concerns, governmental drawdowns, politics, and the actual willingness to change the weather support architecture (jobs, roles and missions, etc.) are just some of the hurdles that have to be overcome to obtain the proposed capability. Decades could pass before fruition is achieved. The SPACECAST 2020 White Paper, "Global View: An Integrated Joint Warfighters Command, Control, Communications and Intelligence Systems Architecture," (U), June 1994, addresses some of these hurdles in more detail and provides a conceptual roadmap to achieve the desired end-state of an umbrella-type, integrated information architecture to provide the communications structure to support the weather information data base concept.[13] Further discussion of the communications architecture will be left to that paper. The focus of this white paper will center on potential technologies and support architectures to be used or are believed to be needed to obtain the proposed weather support capability.

As stated earlier, architecture modifications and operational paradigm changes will be necessary: (1) in the way weather data is collected; (2) in data base fusion and dissemination; (3) in the production of the analysis and forecast products; and (4) in the dissemination of the weather products and information data bases.

In the area of data collection, satellite resolution and sensing capability must be enhanced and observational frequency must be increased to obtain more accurate, gridded worldwide weather and earth-sensing information. To meet this need, the following general modifications and changes are proposed: (1) develop and employ a technologically integrated, joint-use, multispectral, articulated satellite imaging capable (i.e., sensors controlled to look at given locations with variable magnification)[14] meteorological and Earth-sensing polar orbiting satellite system,[15] consisting of four to six satellites evenly spaced in orbit by nodal time;[16] (2) continue to upgrade and maintain on orbit a high resolution, multispectral, articulated satellite imaging capable, US geostationary satellite constellation; (3) develop a quick launch capability to put LightSat weather satellites in long-dwell-over-target orbits, such as geostationary or high elliptical orbit, to support theater commanders during war or major regional contingencies; and (4) continue world cooperative efforts to maintain access to foreign geostationary satellite data as well as satellite and surface-based observations and vertical sounding data.

To continuously develop and update the integrated weather information data bases, high capacity, high speed data processing center(s) will be needed to do the data fusion and dissemination. The processing center(s) is viewed as a centralized facility that can down-link satellite data, ingest ground observations and upper air soundings, and fuse the entire realm of continuously updating data into worldwide gridded information data bases to be sent over the information superhighway. Depending on the type of data base desired, on-board processing of satellite observations can be achieved with foreseen advances in computer processing technology. Under this circumstance, the satellite down-link will receive only processed geophysical products.[17] This concept will be beneficial to a theater commander who launched a weather LightSat and needed near-realtime processed weather information for the theater. Difficulty could occur in the timely fusion of the data with other ground and satellite based observations.

Analysis and forecast product development can be accomplished at various on- and off-ramps of the information superhighway. These ramps will most likely be centralized national weather support forecast centers. These centers will receive, via the information superhighway, gridded observational data bases produced by the data processing facilities. The centers will produce tailored weather forecasts, analyses, and climatology products and gridded data bases for commercial, military, and civilian use and access via the information superhighway. By 2020, the national data processing and

weather support analysis and forecast centers will probably be joint-use military and civilian centers in the continental US (CONUS). Commercial weather information producers will continue to exist, as long as there is a profitable market to exploit.

The development of the information superhighway will be one of the key factors in the product and information dissemination process. The grand vision of the information superhighway depicts it as a "massive client/server and peer-to-peer mesh capable of carrying gigabits, and eventually terabits, of data per second on its trunk lines."[18] Key to the dissemination of the integrated weather data bases onto the information superhighway will be the "back-end servers, networking technologies, client devices, and software applications"[19] at the data processing centers and at the analysis and forecast centers. At the user-end of the information superhighway, communication connectivity in the form of interactive ports and software will be the critical technology needed to obtain the weather data bases from the superhighway.

Looking ahead, several technological hurdles will need to be overcome to successfully build the architecture for the proposed capability. First, the fusion of multispectral cloud data from polar orbiters and geostationary satellites into a universal cloud data base will be needed; the geometry, temporal, and resolution differences between the satellite systems significantly complicates the fusion effort. Secondly, the fusion of special remote sensing data with surface data and vertical soundings will be needed. The key difficulty in this fusion process will be maintaining the currency of the data due to continuous update. The third hurdle is the rapid processing of vast volumes of continuously updating data from surface and satellite sensors. High speed, high capacity computer processing and satellite down link capabilities will be essential to meet the data processing need. Other potential technologies that need to be developed or upgraded include: (1) weather micro-processor receivers with built-in decision-aids designed for specific needs; (2) integrated satellite bus technology and design; (3) development of articulated satellite imaging devices; (4) enhanced high resolution geostationary satellite systems; (5) computer systems architecture that can process trillions of data bytes every hour, (6) forecast model development that will take into account the high-dimensional, non-linearity of the atmosphere,[20] and (7) development of enhanced weather simulation model capabilities for use in evaluating new, emerging systems and operational concepts as well as mission planning, tactical applications of weather information data bases, training, and design and use of satellite systems.[21] More discussions of technological hurdles and potential advances in satellite observation are

contained in the SPACECAST 2020 White Paper "Surveillance and Reconnaissance In 2020" (U), June 1994.[22] Many of the technologies discussed in this paper will greatly enhance remote sensing of the atmosphere and the Earth's surface, especially those enabling magnification of a special area for closer examination and measurement (articulated satellite imaging devices).

Potential Technologies

Now that the proposed capability and its relevance, in general terms, have been discussed; a closer, more detailed look at existing weather support architecture, operational paradigms, and current and potential technologies that may be useful in achieving the integrated weather information data base end-state will be taken. The ideas presented represent a possible future architecture to support the proposed capability.

By the year 2020, with declining federal budgets and the rapidly increasing computer hardware and software technologies, the military and National Weather Service centralized weather support structures will probably consolidate--a major shift from the current operational paradigm. The resulting national weather support structure must then process, develop and disseminate weather information data and provide tailored product support to military, civilian, and commercial weather information users. A very limited number of centralized data ingest and processing centers will be needed to produce the worldwide weather information observation and cloud imagery data bases for transmission via the information superhighway. However, to produce the forecast data bases and specially tailored products, a distributed network of governmental forecast centers pulling the basic weather information off the information superhighway can be used. Commercial weather support companies, who currently obtain weather data and cloud imagery through agreements and purchase requests from the government, will continue to operate as long as they produce a profitable product.

If consolidation does occur between DoD and National Weather Service, it is envisioned that the weather support personnel, at least for CONUS locations, would be governmental civilian employees, in a paramilitary-status, supporting the military mission as a civilian during peacetime, becoming active duty military personnel during war, contingency, national emergency, or possibly exercise. This type of weather support structure already exists for many of our NATO allies (Great Britain and Germany are

prime examples). Benefits from this consolidated paramilitary structure are expected to be reduced manpower, operating and facility costs, enhanced technological performance, and a more focused and rigorous technological development program. Permanently assigned active duty weather personnel, however, will probably still be needed to support forward deployed forces.

To improve observations of the atmosphere and earth, and to help build timely worldwide weather observation and information data bases, high resolution, multispectral, articulated satellite imaging capable, meteorological satellite coverage is needed. Currently, the DoD develops and operates the high resolution, Defense Meteorological Satellite Program (DMSP) which normally maintains two satellites in polar, sun-synchronous orbits at low altitude.[23] The National Oceanic and Atmospheric Administration (NOAA) develops and manages both the low orbit, sun-synchronous (POES-Polar Orbiting Environmental Satellite) and the geostationary orbit (GOES-Geostationary Orbiting Environmental Satellite) programs.[24] National Aeronautics and Space Administration (NASA) operates the polar orbiting LANDSAT remote multispectral sensing satellite. The DMSP and NOAA polar orbiters fly to support respective missions, many of which require similar data. DMSP is driven by strategic taskings while NOAA launches to support forecast model production needs. Unfortunately, DMSP and NOAA often have nodal times fairly close to each other. Thus, timing of satellite coverage around the world is uneven and often leaves gaps of several hours which lessens tactical use of the data and forecast accuracy. LANDSAT is in a different orbit and generally measures the Earth's surface at tasked locations, which usually are not aligned with the weather satellite orbits. LANDSAT, though a civilian satellite, has the capability to provide wide-area surveillance surface data to support theater commanders.[25]

Consolidation of the polar orbiters will reduce costs, enhance technological performance and capability, and provide more frequent measurement of the atmosphere and the Earth's surface. Integrating the polar orbiter missions onto one satellite bus and maintaining four-to-six satellites in uniformly spaced orbits (i.e. nodal times six hours apart or four hours apart, respectively) will provide significant benefit to forecast accuracy and weather support to both civilian and military users.[26] Currently, the atmosphere is vertically sounded from the surface twice a day. Remote sensing from DMSP and NOAA POES satellite systems generally can occur twice a day over a particular region, if tasked. Integrated capability of four-to-six satellites can provide an

average of four soundings for a given location a day, if needed. Increased frequency of vertical soundings will provide a more accurate picture of the atmosphere's structure for use in forecast models. Forecast accuracy should significantly improve since data used in the models will be only four to six hours old instead of the current twelve hours.

The development and launch of higher resolution, enhanced multispectral, articulated satellite imaging capable, geostationary satellites coupled with the incorporation of the 30 minute geostationary satellite images into the polar orbiter data base will greatly enhance the weather support architecture. Tracks of polar-orbiting satellites overlap in mid-latitudes and above so that more frequent coverage is provided for a location at these latitudes. In the equatorial regions, this is not the case; equatorial cloud data will be a few hours older than the higher latitude cloud data. Updating the cloud data bases with geostationary data will improve the accuracy of equatorial cloud depiction which should, in turn, improve forecast accuracy in the equatorial regions.

Currently, the US and other major countries maintain geostationary environmental satellites on orbit. These satellites provide timely cloud cover images (every 30 minutes) that have proven highly beneficial to near-term forecasting applications, both military and civilian. Disadvantages of these satellite images are the decrease in imagery resolution as one progresses away from the subpoint of the satellite, the overall lower resolution of the image, the earth limb distortion of the imagery,[27] and the difficulty in fusing the data into data bases containing polar-orbiter weather data. In the twenty-first century, geostationary satellites must be designed to take higher resolution imagery, provide an expanded multispectral sensing capability, and configured to produce a data flow that is easily fused into a gridded data field for use on the information superhighway.

In addition to the primary geostationary weather satellite system just discussed, LightSat weather satellites, placed in long-dwell-over-target orbits, such as geostationary or high elliptical orbits, must be a commonly available asset for theater military commanders to quick-launch in support of a war or major regional contingency. Even during peacetime, availability of foreign geostationary weather satellite data for a region may not exist. Currently, India refuses to allow any nation real-time access to their geostationary INSAT weather satellite data.[28] This data would have greatly benefited war time weather support during Operations DESERT SHIELD and DESERT STORM. The European Space Agency moved one of their METEOSAT weather satellites further eastward to provide better coverage of the Southwest Asia area to support the Gulf War

effort.[29] This move significantly helped the weather support effort, but the imagery still contained significant distortion over the Southwest Asian region due to the satellite's angular viewing access (i.e., limb of the hemispheric view). Three DMSP satellites covered the theater area providing high resolution satellite updates about every six hours. This satellite support combination met the theater need; however, a CINC-directed, quick-launch geostationary weather satellite would have greatly benefited the nowcasting capability of the forecasters in the Kuwaiti Theater of Operations.[30]

Significant capability enhancement, or possibly new technological design, of satellite down-link capability as well as data ingestion, fusion, and processing capability are necessary. High speed, high capacity computers are required to process the trillions of data bytes coming through the funnel every hour. Process must convert the data into synthesized gridded fields containing several variables to be sent through the pipeline into the information superhighway for further use.

New forecast models and specially tailored products, for both military and civilian use, must be devised to ingest the gridded data and produce a usable product. With increased frequency and coverage of data, the accuracy of forecast models should increase. Expansion of current spectral forecast model capability will be possible due to the availability of more data and faster computers. New modeling techniques and product production are also anticipated, especially those involving high-dimensional nonlinear iterative methods, designed to handle the non-linearity of the atmosphere.[31]

A worldwide ground-based observation and atmospheric sounding network is already in place and overseen by the United Nations' World Meteorological Organization (WMO), but requires upgrade in technical quality and made less manpower intensive. The Air Force maintains the Automated Weather Network (AWN) which is a global, high speed data network used to collect worldwide weather data and disseminate weather information out to DoD and civilian users. A capability upgrade or potentially redesign of the AWN into the information superhighway architecture will be needed to meet the fast-paced weather data requirements of the twenty-first century.

During war time, access to portions of the world weather data may be denied. Surface and upper air observations are critical to military operations, thus, a capability to obtain data from denied areas is needed. One suggestion is to insert, by air, missile, or hand, micro-miniaturized surface weather sensors to measure surface conditions

continuously and transmit data back to a communications relay satellite for collection and dissemination by direct broadcast back to the users or the information superhighway. Also, these sensors will provide ground truth for satellite vertical soundings in the area. A polar orbiting weather satellite or possibly a LightSat geostationary weather satellite, can receive the ground sensor transmission and then generate a vertical atmospheric profile. The sounding could be directly broadcasted to the theater or input to the weather data collection network residing on the information superhighway (figure 2).[32]

In addition, worldwide access to special observation systems, such as the doppler radar and lightning detection systems, must be obtained and expanded. Information gathered will greatly benefit weather information users who must quickly make decisions in situations where severe storms and lightning occurrences endanger

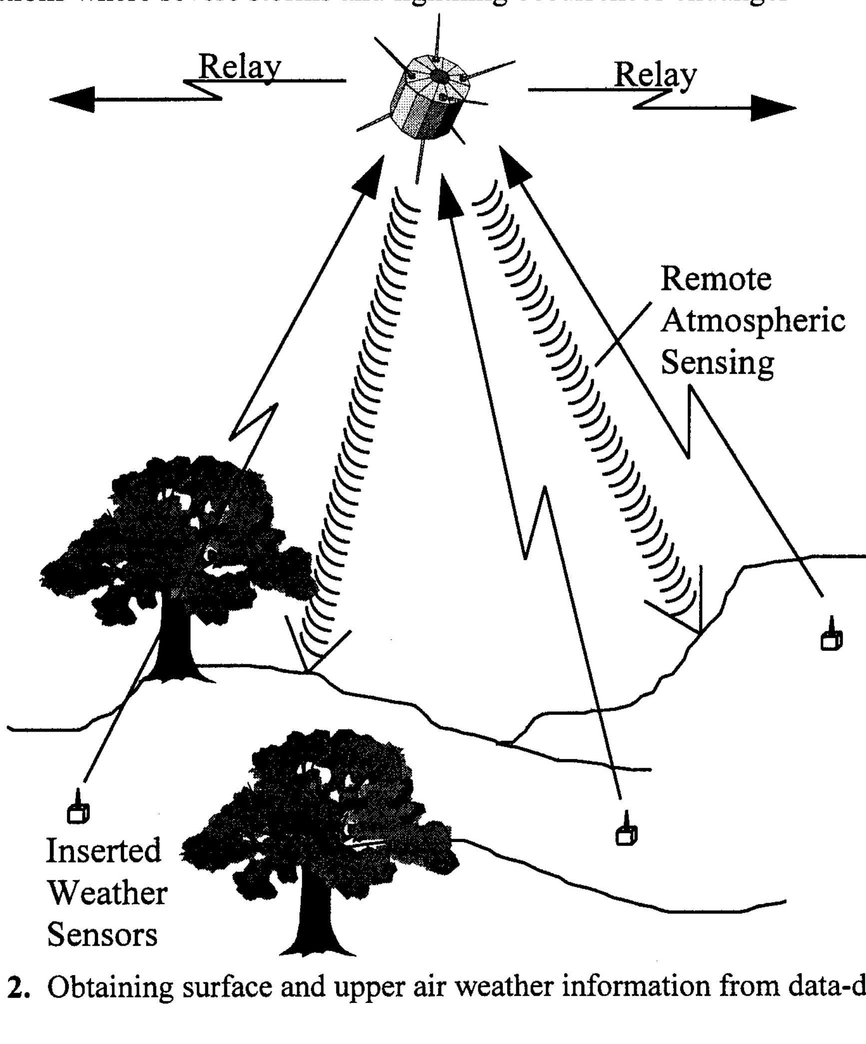

Figure 2. Obtaining surface and upper air weather information from data-denied areas.

operations. Airplane pilots, munitions and fuel supply areas, and community safety concerns are just some potential users who will benefit from access to this information residing on the information superhighway.

Near Term Technologies and Operational Exploitation Opportunities

Currently, three data distribution systems exist that are forerunners of a portion of the future capability envisioned in this paper. These systems are the Air Force's Automated Weather Distribution System (AWDS), the Navy's Naval Oceanographic Data Distribution System (NODDS), and the Air Force Global Weather Center's (AFGWC) Dial-In System (AFDIS). The AWDS is a new generation computer/communications system with a dedicated communications and switching network directly connecting AFGWC with Air Force Base Weather Stations around the world. AFGWC can flow distributed gridded data bases of current and forecast weather information to the Base Weather Stations for in-house analysis and display over a computer terminal. The NODDS and AFDIS systems uses telephone line connections between a user's small computer and the mainframes of the military centralized facilities the Fleet Numerical Oceanographic Center (FNOC) and AFGWC. Processed gridded data fields, tailored graphic displays of weather information, and satellite cloud imagery from the Satellite Global Data Base (developed by AFGWC and shared with FNOC) can be sent from the centralized facilities to the requester. This capability can greatly enhance weather support during operations where access to worldwide weather data is limited to nonexistent. NODDS proved itself during Operations DESERT SHIELD and DESERT STORM. AFDIS is currently undergoing initial employment in the field. AWDS, NODDS, and AFDIS products can be suitable as integrated weather information data bases on the information superhighway, especially if they can be obtained through direct satellite broadcast anywhere in the world using small microprocessors and receivers.

Great strides are underway by NASA, NOAA, US Geological Service, European Space Agency, Japan, and other nations to develop satellite means to observe Earth as an integrated system. The fundamental processes to be observed and which govern and integrate the earth system are the hydrologic cycle, the biogeochemical cycles, and climate processes. The current meteorological satellites and LANDSAT are forerunners of the proposed Earth Observing System (EOS).[33] The EOS program is an evolutionary program with a projected orbital observing capability of 15 years. The mission lifespan

will be achieved via instrument and platform redundancy, and orbital replacement and servicing. NASA will launch two polar orbiting satellites, one in 1996, the other in 1998. European Space Agency will launch a third satellite in 1997 and Japan will follow with a fourth satellite in 1998. Satellite payloads will include sensors for remote sensing of the atmosphere, the earth, and the space environment. Cloud imagery will be possible, but it will not be the primary product. EOS will provide scientists and researchers access to integrated global data bases for the study of the Earth system science.[34] Although the system is not designed for daily operational weather sensing or to provide LANDSAT-type pictures for operational use, the concept is very close to the concept already presented of integrating and consolidating DMSP, NOAA, and LANDSAT satellites into one operational system.

Access to the information superhighway may negate the need for a hands-on local meteorologist to provide forecast support. Nothing, however, will ever replace the human intuition in forecasting or the public, personalized service. As we move into the twenty-first century, interactive graphic and data access to the information superhighway coupled with one's own decision-aid micro-processor, weather support will become more direct, timely, automatic, and user-friendly. For the warfighter, near instantaneous access to global weather information from anywhere in the world will be a critical factor in making and executing battle area decisions faster than the enemy's OODA-loop capability. Fused global weather information must be a part of every warfighter's kit.

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SPACE-BASED SOLAR MONITORING AND ALERT SATELLITE SYSTEM (SMASS)

Overview

Space operations, both manned and unmanned, are in constant jeopardy of mission degradation or failure due to the impacts of space weather (i.e., variability of the near-Earth and interplanetary space environment). The primary driver of the interplanetary space weather affecting earth is the Sun's varying emission of electromagnetic radiation and solar wind plasma (i.e., an ionized gas consisting of protons, electrons, and other heavy, energetic particles ejected from the Sun's outer atmosphere (corona) at a mean velocity of 400-500 km/sec with a mean density of 5 particles per cubic centimeter).[1] Galactic cosmic radiation contributes only 5-10 percent of the total radiation, and thus, is not a major driver of space weather from the earth's perspective.[2] Near-Earth space weather (i.e., within the Earth-Moon orbital system) is primarily the resultant of the Sun's electromagnetic radiation and plasma interactions with the Earth's intrinsic geomagnetic field. The variability of space weather is closely tied to the 27 day rotation period of the Sun and the Sun's approximate 11-year sunspot cycle. During solar maximum (i.e., time of maximum sunspot activity and associated solar flare eruptions), the magnitude of the variability can become quite large, producing extremely hazardous space environmental conditions (figure 1).

Space weather can impact space operations by inducing spacecraft charging, orbital drag variations, and hazardous ionizing radiation effects on spacecraft and astronauts. For example, the Jupiter Pioneer spacecraft encountered severe space weather in the Jovian radiation belts which nearly destroyed many on-board systems.[3] Closer to home, the geostationary Earth orbiting ATS-6 satellite, launched in 1974, recorded static surface potentials (spacecraft charging) as high as 20,000 volts due to severe space weather.[4] Common satellite anomalies induced by space weather include computer processing errors, loss of satellite contact, satellite shut-down, and loss of satellite orientation due to the radiation and energetic particle import on star navigation sensors. Satellite orbits can rapidly decay due to satellite drag resulting from space weather induced higher atmospheric density. Narrow-beam tracking radars can temporarily lose fixes on the spacecraft due to these unexpected orbital changes. Often times the drag requires orbital adjustment to keep the satellite in a usable orbit.[5]

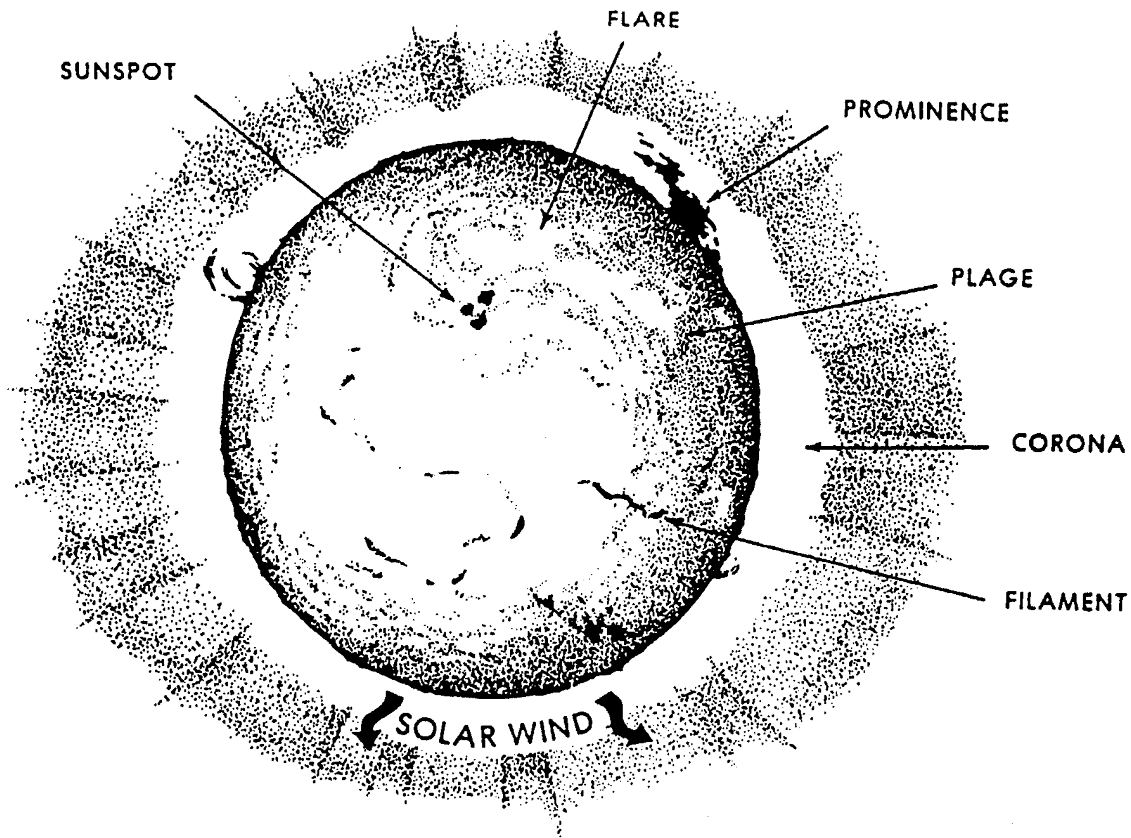

Figure 1. Principal features of the active Sun. The region marked as a flare denotes a highly concentrated, explosive release of energy which appears as a sudden, short-lived brightening of a localized area in the Sun's chromosphere.[6]

The main space weather hazard to human life is the ionizing radiation resulting from exposure to high energy particles. These energetic particles may come from distant stars and galaxies (galactic cosmic radiation); they may be found trapped in planetary radiation belts, such as the Earth's Van Allen radiation belts; or they may be ejected into space by the Sun in the solar wind or more rapidly by solar flare eruptions (figure 2). To put the space weather radiation hazard to human life in perspective, at geostationary orbit, with only 0.1 gm/cm^2 of aluminum shielding thickness, the predicted radiation dose (REM) for one year continuous exposure, with minimum-moderate solar activity, is estimated to be about 3,000,000; using 5.0 gm/cm^2 of aluminum shielding, the REM for one year continuous exposure would be reduced to about 550.[7] (Note: REM = dose

(RAD) x Relative Biological Effectiveness (RBE) of particular ionizing radiation.)[8] Although drastically reduced by shielding, 550 REM for a sample population would cause radiation sickness and about 50 percent deaths.[9] Astronauts protected with only a spacesuit during normal-length extra-vehicular activity at geostationary altitude could receive about 0.43 REM per day under minimum to moderate solar activity conditions, which is sufficient to damage the eyes and other vital organs.[10] Under high solar activity, and most importantly during large solar flare occurrences, daily REM values could be a thousand-fold higher and probably lethal.[11] In comparison, an earth-bound person would have an estimated total yearly radiation dosage in the range of 0.17 to 2.6 REM; the daily dosage would be approximately 4.7×10^{-4} to 7.1×10^{-3} REM (2 to 3 orders of magnitude less than the astronauts daily dosage in our example).[12]

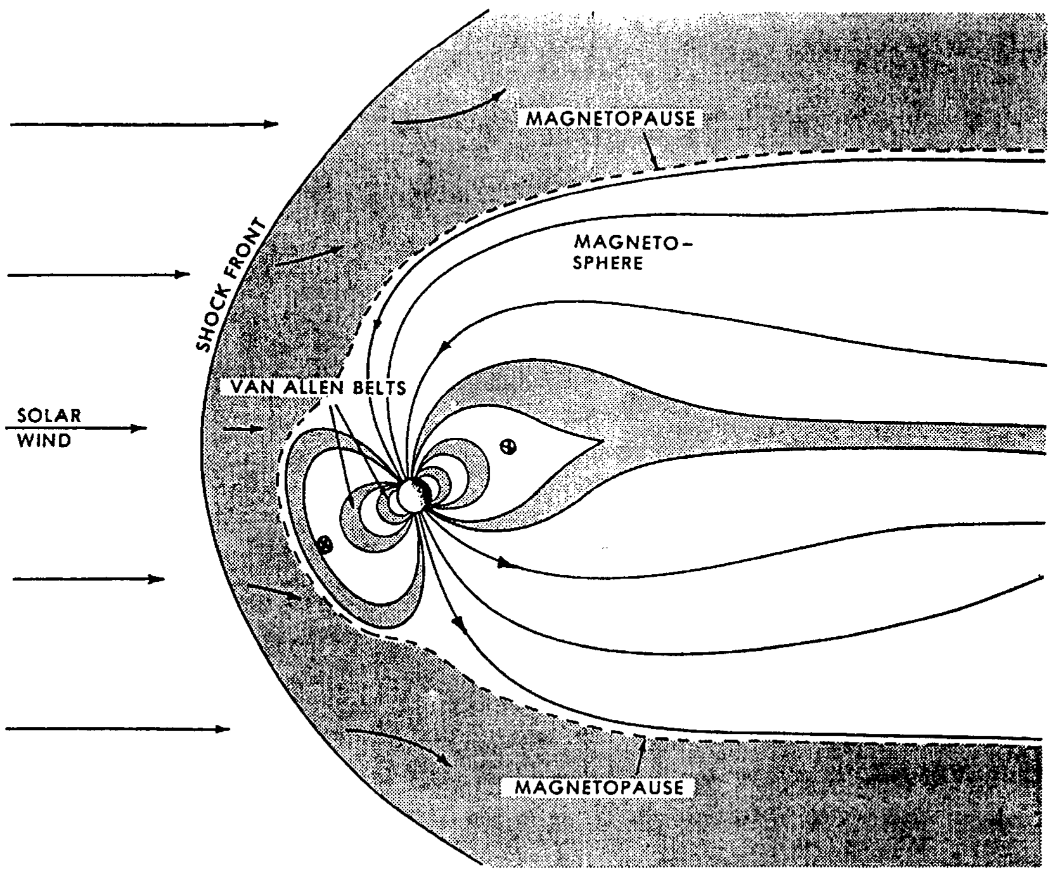

Figure 2. Qualitative picture of the bow shock and magnetospheric boundaries formed by the solar wind interaction with the Earth's intrinsic magnetic field. (Geostationary satellite altitudes are marked by the circled "X").[13]

The USAF Air Weather Service has been providing solar observations and space weather forecasts and hazard alert warnings to support department of defense(DoD) space operators and users since 1962. The support effort is excellent, but the overall capability to provide timely and accurate space weather forecasts is limited. This limitation is caused by: (1) predominately earth-based observational access to the sun; (2) current sophistication of space weather sensor technology and its associated data processing and analysis, and by (3) overall scientific understanding of solar dynamics and interplanetary space physics. For example, influx of solar plasma and electromagnetic radiation into the near-earth space environment can cause the Earth's magnetosphere to go into geomagnetic storming conditions. Geomagnetic storms can severely degrade the radiowave propagation characteristics of the ionosphere, resulting in black-out of communications, radar, and navigation. Current forecast accuracy for predicting geomagnetic storms is in the range of 20 to 40 percent.[14] Forecast accuracy for geomagnetic storm prediction could reach the 80 to 100 percent range with more accurate and timely observations of incoming solar plasma and electromagnetic radiation.[15]

The Need For SMASS

On Earth, accurate and timely weather support provides resource protection and force enhancement for the warfighter; the same holds true in space. If humans expect to effectively and safely operate, and eventually live in the space environment, then significant improvements in space weather support capability are needed. The most beneficial enhancements will involve: (1) continuous observation of the Sun using the entire electromagnetic spectrum; (2) accurate and timely measurement of earth-bound solar electromagnetic radiation and plasma; and (3) rapid processing, analyzing, and disseminating of alerts, warnings, and accurate forecasts of space weather impacts to near-Earth and interplanetary space operations.[16] To achieve the capability enhancements just described, this paper proposes the development and operational employment of a space-based, solar monitoring and alert satellite system (SMASS) to be developed and operated jointly by DoD, National Aeronautics and Space Administration (NASA), and National Oceanic and Atmospheric Administration (NOAA). Other nations may also desire to participate in the SMASS program.[17]

The proposed SMASS will consist of one, potentially up to three satellites, placed in a deep space Earth-orbit ahead of the Earth's magnetosphere bow shock, possibly near the Earth-Sun libration point in a halo orbit (L1, about 220 earth radii out toward the sun (Figure 3)).[18] Direct and continuous optical observation of the Sun as well as continuous measurement of the Sun's emitted electromagnetic radiation and solar wind plasma will be made possible by the proposed satellite system. Some key functions and data collection by the satellite system will include the following: (1) multispectral electro-optical images of the Sun; (2) on-board sunspot mapping and analysis; (3) on-board solar interplanetary magnetic field mapping; and (4) solar flare monitoring and alert capability. The solar flare alert function will include an immediate alert notification communications system, the capability to determine the solar flare's location on the solar disk, and the capability to measure the magnitude of the solar mass and electromagnetic radiation

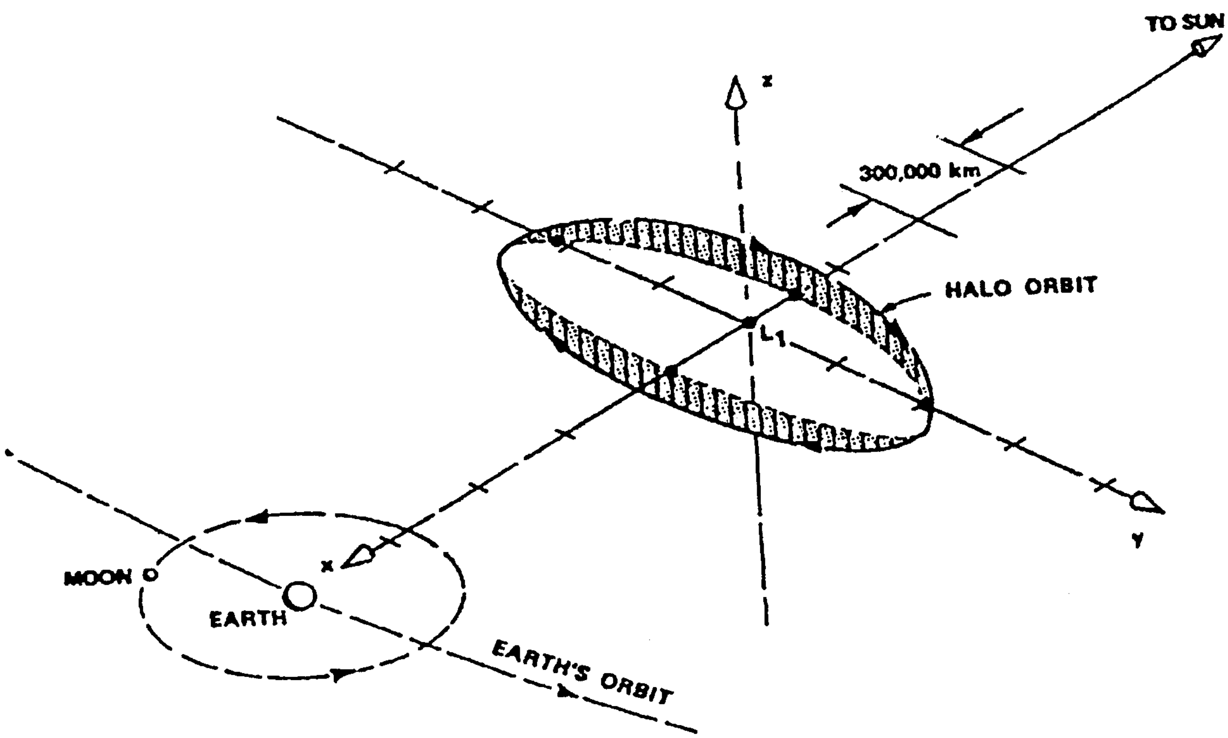

Figure 3. Diagram of a halo orbit around the L1 libration point, located approximately 220 earth radii out toward the Sun.[19]

ejection occurring with the solar flare. Other key functions and data collections by the satellite system will include: (1) plasma particle measurements; (2) direct measurement of the Sun's electromagnetic energy emitted towards Earth to include a direct measurement

of the full disk flux in the extreme ultraviolet (EUV) range; and (3) direct broadcast communications capability as well as dedicated transmission links with space operation centers on Earth and in space.[20]

The proposed SMASS can provide a warning lead time of up to three days for solar plasma ejections that will bombard the Earth or spacecraft and stations operating in space.[21] As stated earlier, these solar plasma ejections can be lethal to manned space operations; magnitude of impact is dependent on the operating orbit, the interplanetary space travel and site location, and the physical protection available to the operators in space. The opposite is true for solar electromagnetic radiation traveling at the speed of light. When we see a solar flare, we are already sensing the increased levels of electromagnetic radiation, but more than likely we have not yet measured increased energetic particle-levels. Therefore, forecast lead time for solar electromagnetic radiation, at least from the Earth's perspective, can not be obtained by direct observation. However, increased knowledge of solar dynamics, gained through direct continuous observation of the Sun, can improve solar forecasting to the point that solar electromagnetic radiation bursts of various wavelengths could be predicted prior to occurrence with some useful lead time.

The Capability and Its Relevance

The payload of the SMASS is envisioned to consist of a multispectral optical telescope continuously monitor the Sun's photosphere, chromosphere, and corona. The following physical processes, as a minimum, will be observed and analyzed by on-board processing: (1) explosive solar flare occurrences; (2) mass ejections into the solar wind caused by low observable solar flares, often optically undetected but indicated by rapid changes in key solar disk features, such as disappearing filaments (i.e., large, rope-like areas of condensed gas suspended in the solar atmosphere) and the on-set of active prominences (i.e., another name for filaments seen on the limb of the Sun which have become active areas of solar plasma ejection into the corona, seen as surges, sprays, and loops); (3) sunspot activity and associated magnetic structure; and (4) coronal hole locations from which the solar wind plasma is spirally ejected outward into space along interplanetary magnetic field lines.[22] A bank of sensors will be on-board to measure the energy content of the solar radiation emitted throughout the electromagnetic spectrum. Besides visible wavelengths (optical), the solar radiation measured will predominately

include x-rays, infrared, near ultraviolet, extreme ultraviolet and radiowaves. Plasma energetic particle counters will also be part of the payload to determine the magnitude of the solar mass being ejected towards earth (figures 4 and 5).[23]

Measurement of EUV radiation is critical to near-earth space weather forecasts since it is this form of short-wave radiation that photoionizes atomic oxygen above 100 km in the Earth's upper atmosphere, producing charged particles called ions, and, thus, the atmospheric region known as the ionosphere.[24] The energy released by the ionization process produces the temperatures of the thermosphere. Essentially, this flux drives the ionospheric and thermospheric conditions that either allows or disrupts radiowave propagation; it also affects atmospheric density, and thus, satellite drag. EUV radiation cannot be measured directly from Earth; its energy is mostly released in the upper atmosphere. The remaining lower EUV wavelengths, not absorbed by the upper atmosphere, are absorbed by the Earth's ozone layer--a fortunate occurrence, since EUV radiation is lethal to man and many other life forms. Currently, EUV flux estimate is only inferred from a known, but not perfect, correlation with the 2800 MHz solar radio flux (F10.7 cm flux).[25] Thermospheric and ionospheric forecast models will significantly increase in space weather accuracy if direct measurements of EUV are available.[26]

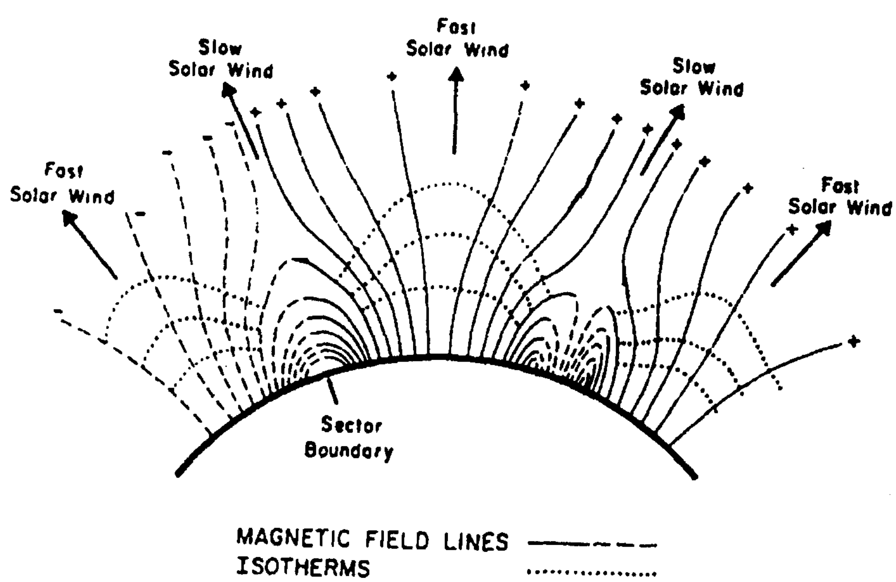

Figure 4. A qualitative sketch of the theoretical coronal structure responsible for high-speed solar wind plasma streams. Magnetic field lines extending outward from the Sun

indicate areas where plasma can flow outward into interplanetary space. Out-flowing regions are called coronal holes.[27]

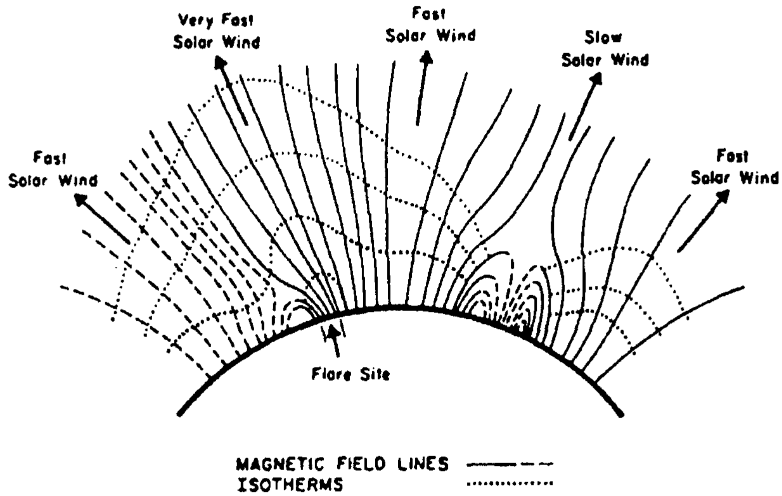

Figure 5. A qualitative sketch of the temporary modification of the coronal structure shown in figure 4 due to flare activity. Diagram assumes the flare was sufficiently energetic to overcome magnetic forces and open a region of the previously closed field lines.[28]

SMASS will have on-board data processing capability, as a minimum, equivalent in capability to the current Cray-system and incorporating the most current computer hardware and software technology available. It is envisioned that the on-board computer can analyze the optical images for critical solar features, and through the use of artificial intelligence schemes, provide high probability forecasts of solar flare eruptions, to include timing and solar disk location, and of coronal hole emission areas for the solar wind. Multispectral, electro-optically-digitized pictures of the Sun as well as on-board analysis products could be transmitted back to a command center, either on Earth or in space, for operational use or further analysis. The radiation and plasma information will be analyzed on-board for alert warning thresholds. Immediate warnings for hazardous increases in flux levels of electromagnetic radiation and plasma as well as associated raw data will be directly broadcasted into space and sent back via direct link to an Earth or space-based operations command center. With the on-board capability to monitor coronal holes, to measure the solar interplanetary magnetic field, and to determine probable areas and timing of solar flares, on-board computer models can generate

forecasts (potentially extending out to 72 hours) of solar plasma wind conditions and radiation flux affecting near-Earth space environment and interplanetary space. Forecasts will be directly broadcasted as well as sent back through direct transmission to an operations center on Earth or in space. The operations center will have the flexibility to task the satellite to transmit various combinations of data packages back to the center. Analysis and forecast capability will exist as a redundant capability at the operations center in case of satellite problems.[29]

The proposed satellite configuration and orbital location was chosen to provide optimum, continuous support to interplanetary space operations as well as near-Earth space environment. As described, the envisioned satellite system will serve as a direct broadcast beacon for space weather data, advisories, and forecasts. Space weather information will be available to all those in-range of the beacon and who have the capability to access the transmission. The concept is analogous to the key aspects of our nation's severe weather warning system--severe weather detection through the use of the doppler weather radar and area broadcast warning through the use of the National Weather Service's Severe Weather Alert Radio Network. Putting the satellite system in geostationary or low earth orbit would require more satellites to provide continuous coverage of the Sun and will deny the total measurement of the radiation and plasma interacting with the Earth's magnetosphere and ionosphere. Interplanetary space travel will experience degraded warning service due to lack of critical data and restriction in direct beacon access caused by the near-Earth space orbital configurations. Furthermore, solar imaging telescopes in low Earth and geostationary orbits will have to overcome more severe background brightness problems due to the Earth's albedo (reflectance) and aurora than they will in a deep space Earth orbit.[30]

Fielding the proposed satellite system will eventually provide monetary benefit by negating the need for the Earth-based network of solar observatory monitoring and alert facilities currently existing; it will also provide space weather alert protection (as stated earlier, a potential lead time of up to three days for solar plasma bombardment) for space station occupants, interplanetary and near-earth space users and operators. Humans in space will use the warnings to take protective shelter. Special temporary shielding may be employed on the spacecraft or satellite to minimize impact of energetic particles. In the twenty-first century, magnetic force field generation might be possible to protect spacecraft by directing the plasma bombardment away from the spacecraft along outwardly radiating magnetic field lines. Increased space weather warning lead-time can

provide space operators and users an opportunity to do alternative communication contingency planning, such as changing raypaths, reverting to different systems less affected, or selectively shutting down systems to avoid electronic damage.

Potential Technologies

Several technologies will need to be developed or upgraded. For example, the development of a satellite-based, multispectral sensor package to monitor the entire solar electromagnetic spectrum will be required. New communications, computer hardware, and software architectures will be needed to: (1) process the data; (2) analyze the data; (3) identify and provide direct broadcast notification of hazardous conditions; and (4) develop and provide forecasts of solar flare occurrences and solar wind plasma conditions. Satellite system protective devices must provide substantial hardening for the satellite so it can withstand the effects of the tremendous electromagnetic radiation and solar plasma bombardment the satellite is trying to measure and analyze. Other additional technological hurdles to overcome will include the: (1) development of a small, high resolution optical telescope suitable for satellite use with the capability of sending electro-optical, digitized pictures of the Sun's atmosphere back to a command center (current solar telescopes are large--tens of feet long); (2) development of a satellite-based, accurate model or artificial intelligence scheme to predict the timing and location of solar flare occurrences; and (3) development of an on-board capability to optically analyze the solar photosphere, chromosphere, and corona for structural features to be used in solar flare and solar wind prediction models.

The envisioned SMASS can be achieved through a phased period of development and employment.[31] During the first phase, the basic satellite data collection system, consisting of a multispectral optical telescope, electromagnetic sensors, and solar wind plasma monitors, will be developed and launched into a deep space orbit. The data collected will be transmitted, without any on-board analysis, back to an Earth-based operations center, such as the current Air Force Space Forecast Center, Falcon AFB, Colorado. Space weather forecasts and advisories will be sent to support space operators and users from the Earth-based operations center. Phase Two of the satellite system evolution will concentrate on the development of the on-board analysis and forecast model capabilities. Development of solar flare and solar wind forecast models as well as schemes to analyze solar atmospheric features (sunspots, flares, plages, disappearing

filaments, coronal holes, etc.) are envisioned to use artificial intelligence schemes coupled with solar physics. These models and schemes will require substantial development effort and experimentation using the data acquired from Phase One of the program to ensure a useful level of accuracy can be obtained. Computer miniaturization and increased speed and capacity will be key assets in hardware development to support the on-board analysis and forecast capability. Phase Three of the program will be the launch of the entire SMASS, as envisioned.

The three phased development proposal generally follows the basic information operations architecture phasing outlined in the SPACECAST 2020 White Paper, "Global View." [32] Key similarities include: (1) the development of the capability to collect data and build data bases on earth (Phase I); and (2) the development of the capability to collect and process data on-board the satellite for direct product generation and transmission to the space operators (Phase III). The Phase II development portion of the SMASS differs from the referenced white paper in that it concentrates on using the collected data to develop more accurate solar dynamic models and forecast algorithms for on-board processing envisioned in Phase III. Realistically, the launch of the Phase I data collection solar monitoring system will probably not occur until the Phase II timing of the Global architecture (2001-2010). The actual launch of the envisioned system corresponds to the proposed Phase III (2011-2020 and beyond).

Near Term Technologies and Operational Exploitation Opportunities

Currently, solar observations are obtained from a network of Earth-based, solar observatory monitoring and alert facilities. The United States Air Force maintains a worldwide alert network of five solar optical observatories and four solar radio telescope observatories to provide continuous monitoring of the Sun for solar flare occurrences. Solar monitoring information is also obtained from several civilian observatories around the world. Solar observations coupled with other key data, such as measurements of the Earth's magnetic field or vertical electron density soundings of the Earth's ionosphere, are fed into the Air Force Space Forecast Center at Falcon AFB, Colorado, for analysis and issuance of space weather advisories and forecasts to military space operators and users. The same information is also sent to the Joint (NOAA) and Air Force Space Environment Services Center (SESC) in Boulder, Colorado. This civilian organization provides similar space weather support to users whose operations depend on knowledge of

geophysical conditions near the Earth. These users will include DoD, NASA, and operators of powerline, pipeline, and high frequency communication networks affected by magnetic field disturbances.[33]

Earth-based solar observatories experience decreased observational effectiveness due to cloud cover and to atmospheric attenuation and absorption of the electromagnetic radiation limiting the spectral monitoring capability to two primary optical spectral lines (Hydrogen-alpha and K-line of ionized Calcium) and a few solar radio wave frequencies. The solar observatory effectiveness is also degraded by local radio wave interference, by the observatory's geographic location (especially latitude), and by international politics. For example, the Air Force's Mideast Solar Observatory, now located at San Vito AS, Italy, has a tumultuous history due to international politics. When located in Tehran, Iran, during the fall of the Shah, the solar observatory was taken over by Revolutionary Guards and the commander thrown into prison for a week.[34] Before capture, the commander was able to hide the Hydrogen-alpha filter, thus disabling the optical telescope, and to smuggle the filter out of the country upon his release.[35] The solar observatory was later reestablished in Athens, Greece, but terrorist threats frequently closed the observatory. The current location of the Mideast Solar Observatory has been operational since 1986.[36]

Current space-based solar observational capability is limited to a few geostationary satellites, such as the United States' Geostationary Operational Environmental Satellite (GOES), carrying sensors to monitor x-ray emissions generated by solar flares, charged particle flux, and the magnetic field surrounding the spacecraft.[37] The Advanced TIROS-N (ATN) satellites, which are NOAA's polar-orbiting weather satellites, carry the Space Environment Monitor (SEM) used to measure energetic particles, protons, electrons, and alpha particles in the satellite orbit; direct solar observations, however, are not made.[38] Similarly, the DoD's Defense Meteorological Satellite Program (DMSP) carries a set of sensors to monitor the space weather conditions in the Earth's ionosphere along the satellite's orbit. Items monitored include: (1) plasma parameters; (2) precipitating electrons and ions causing auroral displays; and (3) location, intensity, and spectrum of x-rays being emitted by the Earth's atmosphere. As with the ATN satellites, direct solar observations are not made.[39] A few solar monitoring satellites have been launched in the past, such as NASA's Orbiting Solar Observatories (OSO) in the 1960s and early 1970s, but they were limited in their mission duration and in their electromagnetic spectrum capability, and were designed for

scientific exploration and not continuous, operational, solar radiation hazardous alert monitoring.[40]

Promising solar imaging technologies for use on the envisioned solar monitoring and alert satellite system are under development. For example, the Phillips Laboratory Space Physics Division Solar Research Branch, located at Sacramento Peak Solar Observatory in Sunspot, New Mexico, is developing a new sensor package, called the Solar Mass Ejection Imager, that could image the plasma ejection from the Sun, trace it through interplanetary space, and provide accurate forecast of arrival at Earth.[41] The Geophysics Directorate of Phillips Laboratory, located at Hanscom AFB, Massachusetts, is developing a sensor, known as the Autocalibrating Extreme Ultraviolet Spectrometers (ACES PL-202), to measure solar EUV from a near-Earth orbiting satellite to an accuracy of 5 percent.[42] Another promising technology, known as the Solar Disk Sextant (SDS), is being developed through NASA and Yale University with the support of Air Force Office of Scientific Research funding. This technology measures the size and shape of the solar disk oblateness to produce accurate measurements of the solar radius. This information when correlated with other solar dynamic processes could significantly improve solar dynamic models and resulting forecasts of solar activity.[43]

Countermeasure requirements for the proposed space-based, solar monitoring and alert system are expected to be negligible, especially if the satellite system is located in a deep space Earth orbit. However, if they do occur, they will include jamming, input of deceptive information, or satellite destruction. This concept is not viewed as a threat that will currently warrant enemy military action. Once the human population has a large permanent residence in the near-Earth space environment, military action could occur, but it is viewed as being unlikely. World-wide agreements are already in-place and have been for years, through the United Nations, to share environmental data. Present day collection of solar data by the civilian and military-owned observatories are routinely made available for world community use. During times of war, data collected by the proposed satellite system can be encrypted or transmitted through secure transmission channels instead of by direct broadcast; this capability will, however, add additional cost to the satellite system.

Space weather is important to all space users. As we exploit space and establish a continuous human presence in space, the importance of knowing the space weather will be critical to human and hardware survival; this cannot be over-emphasized. Incoming

plasma particles ejected into interplanetary space by a solar flare, the most hazardous space weather for mankind, can be as dangerous to one's health and property in outer space as tornadoes are in the midwest United States. As stated earlier, warning lead-time can be achieved for this type of space weather since it can take up to three days for some of the heavier energetic particles to reach the near-Earth space environment. Solar electromagnetic radiation, however, will be essentially sensed at the same time it affects the near-earth space environment since it travels at the speed of light. The tremendous solar data collection capability of the space-based solar monitoring and alert system will substantially increase the space weather support capability far into the twenty-first century.

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[32] SPACECAST 2020 White Paper, "Global View" (U), May 1994. (TS-SCI) Information extracted is unclassified.
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[35] Ibid.
[36] Lt Col Tamzy J. House, personal knowledge based on 18 years experience as a USAF Weather Officer, to include providing operational support to space systems while commanding San Vito Solar Observatory, San Vito AS, Italy, 1986-1988.
[37] P. Krishna Rao, Susan J. Homes, Ralph K. Anderson, Jay S. Winston, and Paul E. Lehr, editors, *Weather Satellites: Systems, Data, and Environmental Applications* (American Meteorological Society, Boston, 1990), 130.
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SPACE WEATHER SUPPORT FOR COMMUNICATIONS

Overview

Ionospheric variability (space weather) significantly impacts ground and space-based communications. In essence, the electrically charged particles of the ionosphere (i.e., the partially ionized portion of the atmosphere starting at about 40 nautical miles (nm) above the Earth's surface) can attenuate, totally absorb, reflect, change direction of propagation, and change the phase and amplitude of radio waves. The magnitude of the impact is dependent on ionospheric space weather conditions resulting from: (1) the variability of the solar radiation entering the upper atmosphere (primarily extreme ultraviolet (EUV)); (2) the solar plasma entering the Earth's magnetic field; (3) the gravitational atmospheric tides produced by the Sun and the Moon; and (4) the vertical swelling of the atmosphere due to the daytime heating of the Sun.[1]

Space weather in the ionosphere becomes more intense and hazardous during solar flare activity. Sudden ionospheric disturbances (SID), ionospheric storms, polar-cap absorption (PCA), and geomagnetically induced storms are forms of space weather resulting from solar flare activity. During these conditions, enhanced levels of energetic particles and EUV enter the ionosphere, increasing atmospheric neutral and electron density through particle injection and photoionization. Depending on the intensity of the variability induced, the resulting space weather could significantly impact radiowave propagation, causing intermittent or a complete blackout of communications, radar, and navigation, primarily in the polar regions and high-to-middle latitudes.[2]

Ionospheric space weather can also be induced by the tilt of the earth's geomagnetic field. This tilt produces anomalous regions in the South Atlantic and over Southeast Asia where energetic particle interactions are occurring with neutral particles at a much lower altitude resulting in increased radio propagation effects.[3]

Ionospheric scintillation, another form of space weather, can cause fluctuations in the phase and amplitude of radio wave propagation. This space weather phenomena causes outages on satellite-to-ground or satellite-to-aircraft transmissions over the frequency range of VHF to L-band, especially in the equatorial belt (+/- 20 degrees latitude).[4] Fleet Satellite Communications (FLTSATCOM), Air Force Satellite

Communications (AFSATCOM), and Navstar Global Positioning System (GPS) are especially vulnerable to this form of space weather (figure 1).[5]

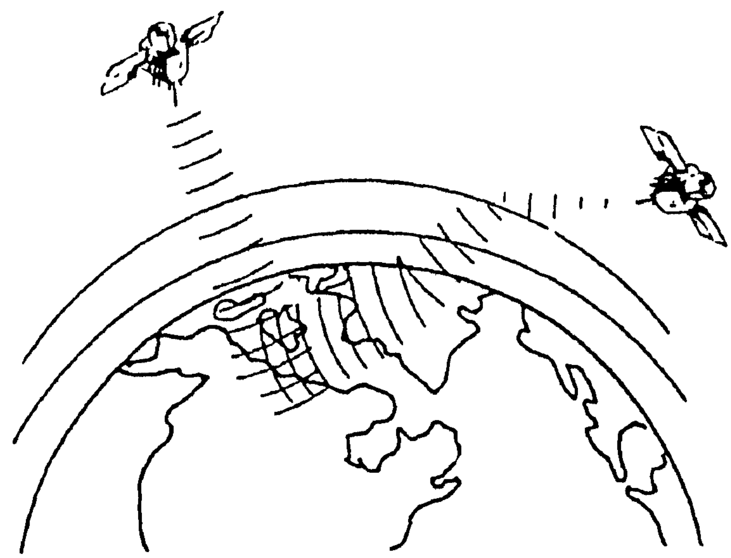

Figure 1. Depiction of ionospheric scintillation affect on GPS satellite transmissions.[6]

Our current capability to provide ionospheric space weather observations, accurate forecasts of space weather conditions, and timely hazard alert warnings is limited. Key factors causing the limitation are: (1) current ionospheric sensing capability; (2) density and frequency of ionospheric observations; (3) sophistication and accuracy of ionospheric models; and (4) current scientific understanding of the physics of the ionosphere-thermosphere-magnetosphere coupling mechanisms. To improve our ionospheric space weather support capability, especially to tactical and satellite communications, our ability to frequently measure the ionosphere vertically and spatially must be significantly enhanced.

The Need For Ionospheric Mapping

To achieve this enhancement, daily, consistent in time and space, worldwide ionospheric mapping capability is required. This capability can be obtained through the following architecture: (1) installation of ionospheric sounders and other ionospheric

sensing devices on department of defense (DoD) global satellite constellations, such as the GPS (altitude of 11,000 nm)[7] (figure 2), and on global commercial constellations (such as the future IRIDIUM system being developed commercially by Motorola) and others in planning or development; (2) installation of ionospheric sounders and sensors on dedicated or host satellites flying in lower circular, equatorial orbits (critical for equatorial scintillation identification and forecasts) between 20 degrees latitude north and south at an altitude of about 400 nm;[8] (3) continued installation of ionospheric sounders and sensors on polar orbiting satellites such as the Defense Meteorological Satellite Program (DMSP); and (4) expansion of ground based ionospheric vertical sounder networks (United States' and other nations'). The data collected from the satellite-based sounders will be down-linked to an operational center, such as the Air Force Space Forecast Center, Falcon AFB, Colorado, for processing and coupling with ground-based ionospheric sounding data to develop a daily, global, vertical electron density profile structure for the entire ionosphere. The other ionospheric sensors in the proposed package will collect additional ionospheric data to include: (1) ultraviolet images of auroral zone and airglow spectra; (2) *insitu* particle counts; (3) kinetic temperature measurements of ions and electrons; and (4) measurements of plasma irregularities.[9] This proposed data collection and distribution architecture parallels the ideas presented in the SPACECAST 2020 White Paper, "Global View." (U), June 1994.[10]

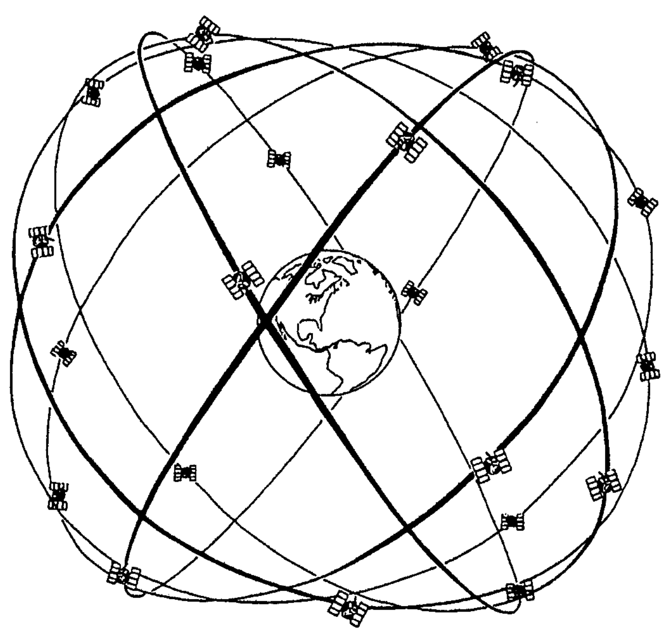

Figure 2. NAVSTAR Global Positioning System constellation.[11]

The frequently replenished ionospheric data obtained from the worldwide mapping capability will significantly improve the timeliness and accuracy of: (1) space weather alerts and warnings; (2) radio frequency propagation forecasts; (3) radio direction finding activities (potentially by an order of magnitude); (4) order of battle assessments;[12] and (5) forecasts for ionospheric scintillation outages affecting satellite communications.[13] Study of the data can bring new insight into the space weather physics, leading to improvement in ionospheric and thermospheric forecast models. Accurate space weather forecasts will greatly assist satellite operators and users in their efforts to improve operational efficiency of their space systems. Current ionospheric forecast accuracies are estimated to generally range between 40-60 percent; daily global mapping of the ionosphere can potentially increase the forecast accuracy range to 80-100 percent.[14]

The Capability and Its Relevance

The GPS constellation consists of 24 satellites in circular orbits just under 11,000 nm above the Earth's surface. Four satellites are in each of the six orbital planes, each plane inclined 55 degrees to the equatorial plane and separated by 60 degrees in right ascension.[15] The replenishment requirements for the GPS constellation with the resultant periodic launches will provide the opportunity to include an ionospheric measurement capability on future production satellites.[16]

The IRIDIUM system, designed to provide worldwide cellular phone access, is still under production; initial launch is expected within the next two or three years.[17] The constellation is projected to contain 66 LightSats (i.e., small, light-weight satellites). Attaching ionospheric sounding devices on this system and other similar systems will significantly increase observation rate and enhance global ionospheric mapping capability.

Forecasting radio frequency propagation is similar to weather forecasting in that large volumes of fresh data, collected over vast territorial expanses, are needed daily to provide condition estimates reasonably accurate and sufficiently detailed.[18] The daily worldwide mapping of the ionosphere will provide the needed data to make accurate forecast reports for diurnal, worldwide, terrestrial propagation characteristics of electromagnetic energy in the 3 MHz to 300 MHz frequency range. The data will also enhance the accuracy of radio direction finding activities. With the daily observational picture of the vertical structure and spatial pattern of the ionosphere, significant accuracy

can be obtained in locating tactical communications sources by mapping those regions in the ionosphere where certain radio signals in certain frequency ranges are readily refracted by the ionosphere. With this knowledge, tactical radio intercepts can routinely and accurately locate and track enemy (friendly as well) platforms, and thus, significantly improve order of battle assessments. Error ellipses are expected to improve by an order of magnitude through the use of the daily worldwide data.[19]

To enhance the overall global ionospheric mapping and to significantly improve our ability to understand, predict, and exploit equatorial ionospheric scintillation, additional remote sensing of the equatorial ionosphere is needed. Certain regions in the equatorial ionosphere are significantly disturbed to cause electromagnetic amplitude and phase fluctuations (scintillation) on satellite-to-ground or satellite-to-aircraft transmissions. The disturbed regions, called equatorial plasma depletions or bubbles, develop after sunset, drift to the east, and persist well past midnight, resulting in a six to eight hour period of potential intermittent FLTSATCOM/AFSATCOM and GPS outages.[20] To obtain the necessary data, an ionospheric remote sensing satellite, in addition to the GPS or IRIDIUM constellation, is proposed to be flown in a circular orbit between 20 degrees latitude north and south at a lower altitude of about 400 nm; however, a remote sensing package can be flown as an add-on sensor on another satellite if a similar orbit is being used.

Information obtained from the equatorial ionospheric sounding satellite or package will be used to forecast the existence and movement of equatorial scintillation regions. With the real-time, daily measurements of ionospheric parameters, such as temperatures, densities, and plasma irregularities, combined with new scientific insight and model development, highly accurate forecasts of future outage locations can be expected. This predictive capability for equatorial ionospheric disturbance regions will improve the reliability of communications within this region through the use of alternate raypaths or relay to non-disturbed regions. Operational users will finally have the ability to uniquely distinguish ionospheric outages from hardware problems or jamming.[21]

Potential Technologies

Ionospheric modeling will be significantly enhanced with the availability of daily worldwide data. Ionospheric vertical and spatial structure will be more readily apparent which can lead to advances in scientific understanding of coupling mechanisms within the

ionosphere, thermosphere, and the magnetosphere. Insertion of daily measurements of the total EUV flux into ionospheric models will also significantly improve model accuracies. (See SPACECAST 2020 White Paper "Space-Based Solar Monitoring and Alert System (U)."[22])

The scientific challenge in understanding ionospheric scintillation is to determine the exact geophysical conditions leading to the onset of plasma depletions at a particular location and time. This challenge relates directly to a major operational FLTSATCOM/AFSATCOM requirement to issue accurate outage forecasts to operational satellite users dispersed worldwide and operating over a wide range of frequencies.[23] The ability to forecast these C^3I outages will overcome a long standing limitation of reliable FLTSATCOM/AFSATCOM in the equatorial region.[24]

A potential exploitation technology can be developed in the twenty-first century once ionospheric variability is understood, globally measured and mapped on a daily basis, and made predictable with a high degree of accuracy. This technology will involve temporarily modifying the ionosphere through insertion of gaseous compounds, such as those containing molecular oxygen (O_2), atomic oxygen (O), molecular nitrogen (N_2), nitrous oxide (NO), helium (He), and atomic hydrogen (H), at certain altitudes and locations to increase the neutral and electron density of a given region through the natural photochemical reactions initiated by the absorption of EUV radiation (figure 3).[25] This effect, however, can also be enhanced by shooting a high energy laser, microwave, or particle beam (wavelength will be dependent on gaseous compounds used)[26] into the chemical insertion region to accelerate the photoionization and dissociative recombination processes. End result from the chemical insertion will be increased electron density having a jamming effect on the enemy's radio wave propagation capability due to absorption of the wave energy by the charged particles in the enhanced ionosphere. The downside is that your own communications can be affected as well.

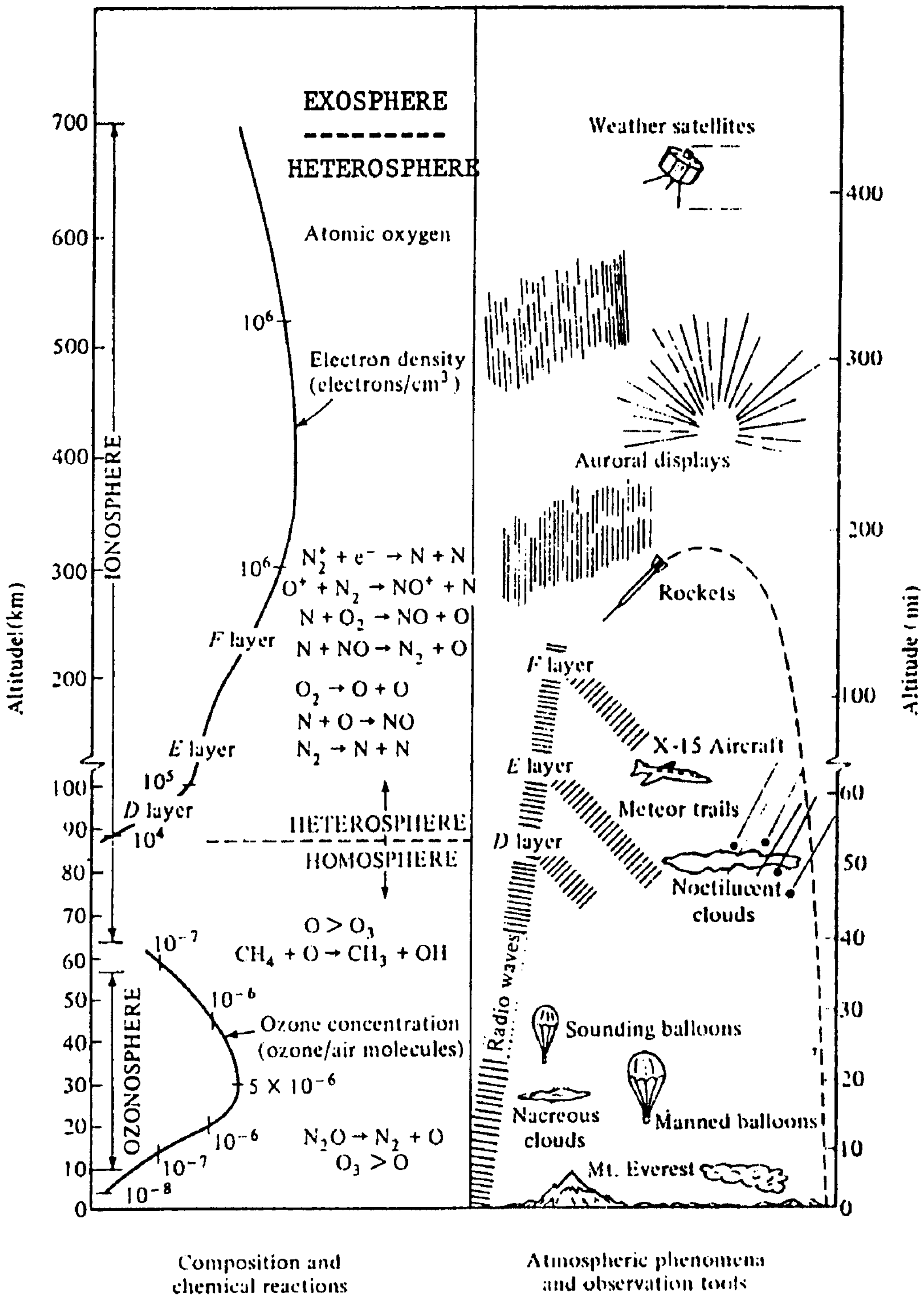

Figure 3. Atmospheric vertical structure, chemical regimes, associated atmospheric phenomena, and weather observation tools.[27]

Near Term Technologies and Operational Exploitation Opportunities

Currently, Earth-based ionospheric sounders (recorders) can measure and produce excellent vertical profiles of electron density through the lower half of the ionosphere. The upper half of the ionosphere, unfortunately, cannot be measured by the sounder because the signal is either reflected back by the level below the maximum electron concentration or absorbed. To measure the upper half of the ionosphere, satellite-based ionospheric sounders and other sensing devices must be used.[28]

Satellite remote sensing of the ionosphere exists today as a capability, but it is limited in coverage, frequency, type of data collected, and timeliness. Some low-earth orbiting satellites, such as the DMSP (currently two on-orbit), carry ionospheric sensing devices. In the case of the sun-synchronous, polar-orbiting DMSP, a set of four sensors, known as the Ionospheric Plasma Drift and Scintillation Monitor (SSIES), measures plasma parameters such as ion and electron temperatures, densities, and plasma irregularities.[29] The DMSP also carries a Precipitating Electron/Proton Spectrometer (SSJ/4) that detects and analyzes electrons and ions precipitating into the ionosphere producing enhanced auroral displays. This information provides critical knowledge of the state of the polar ionosphere for communications, surveillance, and detection systems such as the Over-The-Horizon radar that propagates energy off, or through the ionosphere.[30]

New upper atmospheric models are under development at various universities and laboratories around the world. As these models develop, they will eventually be incorporated into global circulation models that will have the goal of specifying worldwide ionospheric and thermospheric conditions. The US Air Force's Phillips Laboratory is currently developing a new ionospheric model, known as PRISM, which will eventually be used operationally by the Air Force Space Forecast Center at Falcon AFB, Colorado, to forecast ionospheric space weather.[31] The accuracy of this and other models will be significantly enhanced with daily worldwide mapping data of the upper and lower ionosphere, achieved through space-based ionospheric soundings coupled with Earth-based ionospheric sounder data. The ultimate goal of these models will be to provide more accurately, for example, current and forecasted electron density profiles, atmospheric densities, and auroral disturbance locations. Space operators of communications, radar, and navigation systems as well as operators concerned with predicting satellite orbit already use current and predicted space weather information to more efficiently use their assets; however, the estimated accuracy of the current

ionospheric modeling capability is about +/- 25 percent, putting space weather forecast accuracies in the general range of 40-60 percent correct. Daily, worldwide mapping of large volumes of frequently refreshed ionospheric data can reduce modeling error significantly, resulting in potential space weather forecast accuracies in the range if 80-100 percent correct.[32]

The Space Forecast Center provides operational space weather support to DoD space operators and users in the form of bulletins/alerts and forecasts of space weather conditions of the near-Earth space environment. Ionospheric sensing is critical to their capability to provide support.[33] Accuracy of products is degraded due to the lack of near real-time data and worldwide coverage for a given time in space. With a worldwide data base, frequently replenished throughout the day, accuracy of ionospheric space weather products will significantly increase, possibly by an order of magnitude. To take advantage of the increased data availability, from all sources, the Space Forecast Center will need faster and more accurate forecast models (e.g., ionospheric, magnetospheric, thermospheric, solar, satellite drag, etc.) coupled with a high speed, high capacity data processing and product development capability.[34]

The proposed use of the GPS and/or IRIDIUM constellations as well as the launching of an equatorial ionospheric sensor are considered to be a joint-use/dual-use venture among civilian, DoD, and commercial interests. All share similar communication concerns, and oftentimes communications systems are jointly used, thus, all need the same type of information to efficiently use their respective systems. Data collected is expected to be made available for worldwide use unless threat dictates encryption or some type of control. Daily global mapping of the ionosphere will provide significant improvement in the accuracy and timeliness of space weather forecasts, alerts, and warnings for both DoD and civilian space users and operators. The GPS and IRIDIUM constellations provide an access opportunity that must be pursued.

Notes

[1] Thomas F. Tascione, *Introduction to the Space Environment* (Department of Physics, USAF Academy CO, 1984), 175.
[2] Ibid., 176.
[3] Ibid., 183.
[4] Ibid., 225-227.
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[8] Edward J. Weber, Technology Abstract Paper A152.
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[15] 21st Crew Training Squadron, *Space Operations Orientation Course* (AF Space Command, Peterson AFB CO, 1993), 153.
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[27] A. Miller and J. C. Thompson, *Elements of Meteorology (2nd Ed)* (Charles E. Merrill Publishing Company, Columbus OH, 1975) reprinted in Thomas F. Tascione, *Introduction to the Space Environment* (Department of Physics, USAF Academy CO, 1984), 142.
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[30] Ibid., 125.
[31] R. E. Daniell, "Parameterized Real-time Ionospheric Specification Model," *PRISM Version 1.0, PL-TR-91-2299*, Phillips Laboratory, Geophysics Directorate, 1991.
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[33] Ibid.
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SPACELIFT: SUBORBITAL, EARTH TO ORBIT AND ON-ORBIT

Overview

A vision for the future: In 2020, aerospace forces will be a reality. A notional composite aerospace wing, based in the continental United States (CONUS), would include a squadron of rocket-powered transatmospheric vehicles (TAV). These Black Horse[1] vehicles, derived from the Question Mark 2[2] X-vehicle shown in figure 1 and described later in this paper, will be fighter-sized airframes capable of placing an approximately 5,000 pound payload in any low earth orbit (LEO), or delivering a slightly larger payload on a suborbital trajectory to any point in the world. A Black Horse vehicle could accomplish either task within one hour of completion of mission planning, assuming that the payload was available at the base and the vehicles were on alert. When operating in support of a war-fighting commander in chief (CINC), the aerospace wing will thus have the capability to put mission-specific payloads on orbit (mission-tailored satellites) or on target literally within a few hours of identification of a need. Most missions--except some suborbital operational and ferry/deployment missions--will require aerial propellant transfer from modified KC-XX aircraft.

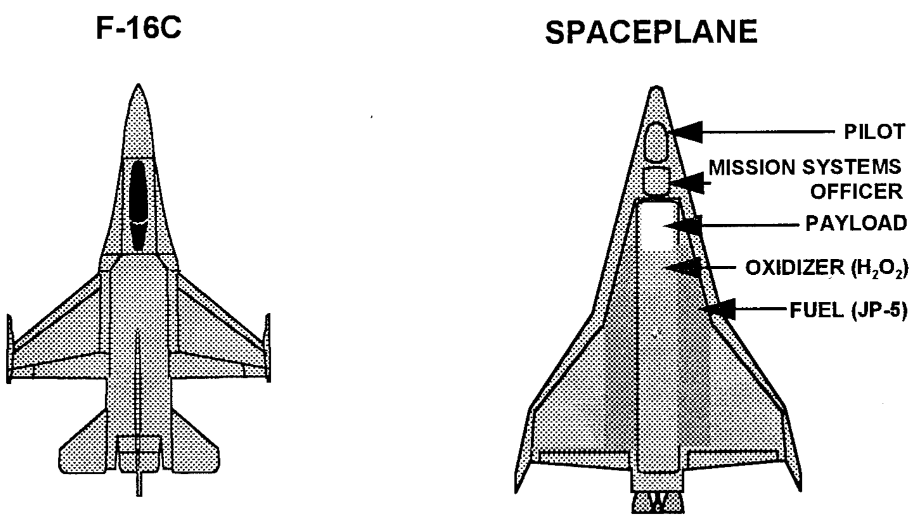


Figure 1. The First Black Horse TAV: "The Question Mark 2" X-Vehicle[3] (Planform Comparison with F-16C)

These aerospace craft will use noncryogenic propellants--standard jet fuel and hydrogen peroxide--and will be designed for maximum logistics compatibility with the rest of the wing.

Maintenance and ground operations for the TAV will require no greater specialized skills than any other aircraft in the wing. TAVs returning from a mission would normally be serviced and returned to ready-for-flight status in less than a day, and could be surged to fly multiple missions per day if necessary. If tankers were prepositioned in theater, TAVs could also fly high priority global cargo delivery missions.

To fully exploit the TAV's capabilities, designers will adopt a new approach to satellite design, one that maximizes use of advances in miniaturization and modularity. Most space systems' designers thus take advantage of the vastly lower cost-per-pound to orbit (less than $1,000 per pound) that the TAV concept provides. Orbital payloads that are too large to fit in a single TAV can be designed as modules, launched in pieces and assembled on orbit.[4] Some high value satellites will be serviced, repaired, and modernized in space by space tugs which will move payloads launched on the TAVs to the mission orbit. With space launch and operations made routine by the TAV, multiple new uses for space systems will emerge, and the design cycle for new systems will be greatly reduced. Such systems will be less expensive, simpler and quicker to make, cause less concern if one does fail, and allow more rapid inclusion of emerging commercial technologies. The ability to orbit, upgrade or even retrieve dedicated, special purpose space support capabilities quickly and (relatively) inexpensively will dramatically change space operations. Satellites will perform navigation and most housekeeping functions autonomously. Central ground sites will monitor, update software, and assist these satellites in identifying repair requirements. Theater forces will task the mission payloads on these satellites directly by using deployable ground systems that require less lift into theater than 1990s communications/data display terminals. The result will be an array of space systems and operations that are fully integrated into global operations.

The description above is not science fiction. It is an entirely plausible outcome of the development program described in this paper. The initial reaction of many readers to the assertions above and the Black Horse TAV concept in general is that it is too good to be true, and that the claims are reminiscent of Shuttle or NASP promises. In fact, Black Horse is substantially different in concept from either of those systems, and the numbers and assertions in this paper are based on a preliminary but iterated design (i.e., several steps beyond a point design) performed by technically credible engineers. Although this paper does not present all the details of their efforts, some additional information on who did the design work, what methods they used and what

assumptions they made is included in the attachments; references are included in the footnotes. Following a brief discussion of the current lift problem, later sections explain the steps needed to produce operationally effective TAVs and the associated capabilities.

The United States must have assured and affordable access to space to expand or even sustain space operations. This means being able to place useful payloads in all relevant earth orbits with high probability of launch success and operation on orbit within hours instead of months or years. It also means the ability to operate flexibly in and through space to accomplish both manned and unmanned missions in support of US national and military objectives.[5] By almost any measure, the current US space lift (earth to orbit) capability is not sufficiently robust. Worse, it is not improving. Suborbital (operations through space) and orbital maneuvering capabilities are almost nonexistent. If the United States is to make full use of space in the next century, military planners must address these shortfalls.

This paper proceeds from the assumption that assured access to space is crucial for many reasons: to enable future innovative ways of supporting combat forces, to counter threats from unfriendly space-faring nations, and to create the conditions for a commercial market that may ultimately support and drive rapidly evolving space technologies. Numerous studies[6] and other white papers in the SPACECAST study[7] are available to support this assumption. Ultimately, expanded military, civil, and commercial use of space depends on assured and affordable access to space.

A review of the limitations of current launch systems suggests several specific problematic areas:

- Current systems have severely limited abort capability because of such things as their predominantly ICBM heritage and the use of solid rocket boosters.
- Use of disposable hardware, manpower intensive operations, and the design of US lift systems in general results in large recurring launch costs.
- There is little or no standardization of launch vehicles, their interfaces, spacecraft buses, or payload interfaces.[8]
- Tailoring rockets to fit payloads is costly, wasteful, and unnecessary.[9]
- Solid rockets and disposable hardware are generally not environmentally friendly.
- The current huge and highly specialized launch infrastructure (ranges, launch pads, personnel, etc.) causes expensive, lengthy, and unresponsive launch schedules. Unless an alternative is discovered, this launch infrastructure will be archaic well before 2020.
- Space launch and operations procedures are overly complex and nonstandard, requiring "white coat" specialists instead of "blue suit" operators.

- Launch operations are "serial" events. One payload and one (dedicated) launch vehicle are readied interdependently and step by step, a process that does not allow parallel preparation of spacecraft and launch systems for flexible launch scheduling.
- The US does not have a flexible, operationally responsive space launch system or the capability to reconstitute even a limited capability on orbit in response to a crisis or loss (deliberate or accidental) of any US space system.

This paper does not propose a new national space policy, a new space lift policy, or a "silver bullet" solution that provides unlimited or unconstrained lift. Rather, this paper proposes an alternative architecture of space lift and suborbital and on-orbit vehicle capabilities that will enable the country to perform new missions in space, provide a responsive and resilient space lift/operations capability that is increasingly acknowledged as militarily essential,[10] permit an escape from the current vicious cycle of cost-weight-size-complexity-risk-delay that frustrates US government space systems, and offer the *potential* for future commercial exploitation that would not only result in vast new commercial opportunities, but would logically drive development of even better space system capabilities.

This paper proposes a spacelift system that can put usable payloads on-orbit affordably, has extremely high operational utility, is responsive, requires little or no specialized infrastructure, operates like an airplane, and has the potential to change the approach to space as surely as the DC-3 changed air travel. The paper also addresses potential suborbital missions that such a system would allow; discusses different ways of deploying, servicing, and redeploying space assets once they are on-orbit; and explains why this is desirable in some (but not all) cases.

If our nation has no desire for expansion in the use of space (either militarily, scientifically, or commercially) it can no doubt continue tinkering with existing launch systems and gradually refine procedures to gain small, incremental improvements in efficiency. This would commit the United States to an ultimately self-defeating cycle: the continuation of increasingly large and complex space systems, technologically obsolescent as soon as they become operational, and ever fewer yet higher-performance launch systems to put them on-orbit. The great risk, cost, and difficulty of replacement associated with failure of one payload during launch or while on-orbit demands increasingly burdensome and unwieldy oversight focused on ensuring that nothing can possibly go wrong. In other words, not only will a policy of business as usual not enable a breakthrough in the use of space, it may ultimately cause some existing uses of space to become unaffordable and unattractive.

The SPACECAST lift team recommends DOD proceed with a modified space development program that emphasizes the lift and on-orbit operations technologies highlighted later in this paper. This program must emphasize, above all else, increased operational flexibility and a concomitant reduction in specialized infrastructure. The top priority should be an X-program to prove the Black Horse transatmospheric vehicle concept. The entire cost of such a program would be less than $150M (using estimates discussed later in the paper). In comparison, a single Titan IV launch costs $325M.[11] This type of system, although not capable of meeting all lift requirements, offers great potential for a breakthrough in making space operations routine and introduces multimission capability. It stands above all other spacelift ideas evaluated.

The Capability and Its Relevance

The Missions

A TAV, like the airplane before it, has the capability to perform many different types of missions. This section discusses the possible uses of a TAV, as well as complementary auxiliary capabilities. The TAV concept described below is not intended to be all things to all people; in fact, SPACECAST explicitly recognizes that one system is unlikely to fully satisfy mission needs in every area. However, the TAV can perform a subset of missions across several mission areas. In this sense it is like the C-130: basically a transport airframe, but with AC-, EC-, KC-, MC- and other versions. SPACECAST believes that the TAV can improve on this by using modular, interchangeable mission modules (satellite or weapons dispensers, for example), so that the same airframe, flying very similar mission profiles, provides a flexible, responsive multimission capability. This capability, discussed in more detail below, provides tremendous leverage in achieving global reach, global power, and contributes to the overall SPACECAST concept of "Global View".

The core of the proposed space lift and transportation architecture is an innovative space access capability that can operate like an air transportation system. The US space transportation capability of the future should include systems for moving payloads around, within, or through space (suborbital, orbital, or return from orbit). SPACECAST 2020 proposes pursuing a space lift development strategy that provides solutions to the country's most pressing problems, while encouraging (but not assuming) future quantum improvements in space transportation technology.

Space Lift. If launch of a satellite becomes a less complex, less time-consuming and less costly task, engineers can design spacecraft for shorter lifetimes with ease of upgrade or replacement. Shorter lifetimes would reduce fuel requirements, much of the on-board redundancy, and other elements related to design life. Designers could avoid much of the current cost redundancy and complexity, creating smaller, less expensive, more technologically up-to-date systems. Evolving toward such systems would make replacements easier to produce and launch, and the consequences of an on-orbit failure could be remedied as soon as a satellite was available. Satellites that must be large for physical reasons (e.g. optics like the Hubble telescope that do not use interferometry) could be designed modularly and assembled on orbit. To take full advantage of this capability, the US would have to revisit most of its basic assumptions about space operations, starting with the type of space lift system.[12]

It is important to note that a single system will not satisfy all needs, just as variants of a single airframe do not perform all air missions. A Black Horse type TAV will probably never launch a MILSTAR satellite. Also, transitional measures may be necessary to preserve operational capabilities until new technology systems come on line. This will undoubtedly include expendable launch vehicles in the near term. SPACECAST believes that the approach outlined below, while not addressing all spacelift problems, provides the maximum potential payoff approaching 2020 and for many years beyond.

Any proposed lift system must address the operational concerns and problems highlighted earlier. Specifically, to be militarily useful, a future lift system must be responsive (capable of launch on demand), highly reliable, able to abort a launch without destroying the vehicle (soft abort), resilient, flexible, logistically supportable, and easily operated. An overriding concern for all users—military, civil, or commercial—is that the system be affordable. These factors can be difficult to translate into specific numbers, so rather than set quantitative goals, this paper will seek a system that offers a recognizable qualitative improvement in the launching of payloads into space. Later sections of the paper describe the Black Horse TAV concept in some detail, using numbers from the initial design. These numbers show the capabilities of an X-vehicle designed with current technologies, and should not be seen as the upper limit of the concept's capabilities.

Force Application Mission. A version of the TAV contributes to our national military strategy by allowing the United States to rapidly respond worldwide to future threats with overwhelming offensive firepower. The system described in this section provides the National Command Authorities (NCA) and the CINC the ability to accomplish strategic-level effects within approximately an hour without using weapons of mass destruction. Rapid vehicle recovery,

rearming, and re-launch on subsequent missions allow the CINC to continue the offensive through decisive follow-on attacks, thereby reducing the effectiveness of enemy interference with reconstitution and recovery attempts. The effects achievable by this vehicle have the potential to escalate the pace of war fighting beyond SPACECAST's projection of future threat capabilities. The system capitalizes on three specific offensive advantages:

o Speed and surprise. The greatest single advantage of this weapon is surprise. Strategic surprise results from the ability to strike enemy targets at any depth with little or no warning. Because kinetic energy multiplies the effects of any weapons delivered from a suborbital trajectory, the weapons themselves can be small (e.g. brilliant micro-munitions) and potentially a single vehicle can simultaneously strike a large number of targets. Operational surprise results from the rapidity of the completed attack, which may be timed to catch an adversary in the process of deployment or employment of inadequately prepared forces. Tactical surprise results from a variety of suborbital profiles these vehicles can use to exploit gaps in an enemy's defense. The speed of the system--the ability to put force on target anywhere in the world in a matter of minutes--also converts the global reach of the system into a form of "presence" which does not require constant forward deployment of forces.

o Mass, economy of force, and persistence. This concept can rapidly complete a multi- (perhaps even multithousand) aimpoint strategic attack with a small fleet of appropriately armed TAVs. The exact number will depend on vehicle payload capacity, final weapons designs, and cost. Rapid revisit times allow continued pressure on the enemy. The concept also contributes to solving the current concern of handling multiple major regional contingencies, since the surge rate of the weapon system should allow destruction of at least two widely-dispersed regional opponent's key centers of gravity within several days. Finally, the simultaneous presentation of thousands of small reentry vehicles to a surprised and defensively helpless adversary will likely overwhelm the enemy, thus ensuring the success of our nation's objectives.

o Synergy. The vehicle's ability to employ a variety of weapons allows tailored effects to prepare the battlefield for other weapons systems or to act as a force multiplier allowing ground, air, and sea forces unimpeded access to the battlefield to accomplish follow-on missions. Results can also provide synergistic effects for other national instruments of power.

<u>On-orbit Operations Mission</u>. Putting things on orbit (into low earth orbit in particular) does not always satisfy operational demands. Some satellites must be lifted to higher orbits, and some key space assets may require redeployment from one operation to the next (alter orbits). Missions to

retrieve high-value assets for repair or upgrade (remotely on orbit, at a space station, or back on earth); to resupply space platforms with things like fuel, food, or weapons; or even to collect space debris and "dead" satellites from highly populated orbits are also possible.

As a result, the US may need a system for transportation between low earth orbit and other orbits. This is essentially an extension to concepts already studied by NASA and DOD. SPACECAST believes that these type of systems complement any lift concept, permitting either larger payloads for a given booster or a given payload to be launched on a smaller system. For the TAV concept, postulation of a separate on-orbit transportation system opens up additional missions, but it is not a requirement for the TAV to perform the basic missions described in this paper.

The Vehicle

Design of a vehicle to accomplish multiple missions is seldom easy. The history of the F-111 serves as a strong warning, as do our nation's so far unsuccessful efforts to accommodate all space users' launch requirements on a single vehicle.

The critical factor in aerospace vehicle design, as in air and space, is ensuring that the mission profile (range, maneuverability, type of payload, etc.) and the performance requirements (speed and amount of payload among others) of the proposed multimission vehicle are compatible. If they are, increased operational flexibility and cost savings through common logistics and operational procedures become possible. The SPACECAST team believes that this <u>is</u> the case with Black Horse vehicles for both the launch of spacecraft and the suborbital delivery of weapons or cargo. As mentioned earlier, the C-130 is a good analogy in terms of design philosophy: simple and as rugged as possible, not necessarily the highest performance system, but inherently capable of multiple missions.

<u>Spacelift Options</u>. The size of the payload put into orbit by a launch vehicle should not drive the launch system design. In fact, small spacecraft have many potential advantages, mentioned at the beginning of the paper. Cost-per-pound to orbit should be a key measure, and if the cost is low enough, almost any mission payload can be repackaged to fit a smaller launch envelope, or accommodated on several launches if need be. Those payloads that absolutely must have a specific size launch vehicle will probably never be affordable, although overriding national security concerns may still require their launch.

The strategy advocated--reducing payload size for a system that produces low operating costs--rests on four assumptions. First, the technology that drives space payloads (sensors, electronics, software, etc.) is advancing rapidly and even accelerating. This puts large, complex satellites (because of their long design and build cycles) more vulnerable to obsolescence on orbit and favors an approach that regularly places more up-to-date systems on orbit. Second, these same technological advances increasingly allow more capability to come in smaller packages: modularity, interferometry, bistatic radar techniques, and other technologies may even allow things traditionally seen as requiring large monolithic platforms to be put in space incrementally and either assembled on orbit or operated as a distributed system. Third, economies of scale have proved elusive in space systems. Large boosters are not appreciably (an order of magnitude) more cost effective (dollars per pound on orbit) than small boosters, and no projected demand or incremental improvements will significantly (again by an order of magnitude or more) reduce the cost of current boosters. Finally, military space operations will be increasingly subject to fiscal constraints; many national security requirements may no longer justify performance at any cost.

Even making these assumptions, there are several possible alternative systems, most of which are familiar. These include Pegasus, Taurus, other light expendable launch vehicles, converted sea launched ballistic missiles launched from sea-based platforms, hybrid (mixed solid-liquid propellant) rockets (also expendable), a variety of reusable vehicles from National Aerospace Plane (NASP)-derived systems to DC-X-derived single-stage-to-orbits (SSTO) and carrier-orbiter concepts like the German Sänger, Boeing's Reusable Aerospace Vehicle (actually a trolley-launched system), and even cannon or railgun launch. A new idea with potentially greater promise is the air-refuelable, rocket-powered Black Horse TAV.

Table 1 is a comparison of several different launch systems that offer at least the potential for a qualitative improvement in space launch. Consistent with the philosophy outlined above, it does not include heavy-lift systems. A more complete description of the capabilities and assessment of these systems is in Attachment A. The Black Horse concept is described in more detail below.

Table 1.
Qualitative Launch System Comparison

System Capability	DC-X SSTO	Black Horse	Pegasus	Taurus	Sea Launch	Gun Launch
Responsiveness	Good	Excellent	Good-Ex	Poor-Good	Poor-Good	Excellent
Flexibility	Good	Excellent	Fair	Poor	Fair	Poor
Soft abort	Fair-Good	Excellent	None	None	None	None
Resiliency	Fair	Good	Fair	Fair	Fair	Good
Logistics	Fair	Good	Fair	Fair	Fair	Poor
Reliability	Unknown	Unknown	Fair	Fair	Fair	Unknown
Ease of operations	Good	Excellent	Fair	Fair	Fair	Fair
Environmental	Excellent	Good-Ex	Poor	Poor	Poor	Fair-Ex
Cost (lbs to orbit)	Good-Ex	Good-Ex	Poor	Poor	Poor	Excellent

Which Kind of System is Best? Most of the alternative systems listed above actually do not offer a qualitative difference in the launching of satellites. Pegasus, Taurus, other expendables, and hybrid rockets fall into this category. A qualitative difference is important because even the most ambitious recommendations for improved conventional (expendable) boosters do not offer more than a 50 percent reduction in cost-per-pound to orbit,[13] and in most cases still rely on antiquated range support systems and to a lesser extent launch procedures. Small expendables, though more flexible and more operationally effective than large boosters, typically cost even more per pound to orbit. In making an eventual system acquisition decision, planners will have to carefully compare the life cycle costs of reusable systems with that of mass produced expendables; such a comparison is beyond the scope of this paper. It is worth mentioning, however, that one of the hidden costs of expendable rockets, particularly those using solid propellants, is environmental. Although difficult to assess, adverse environmental impact may be an overwhelmingly negative factor in future mass use of small expendable launch vehicles.

Cannon/railgun systems may be attractive in terms of cost-per-pound to orbit, but have some severe limitations. Payloads must withstand accelerations of 1000 Gs or greater (this does not facilitate building less costly satellites with fewer constraints on the use of commercial parts), and the US would become more, not less, dependent on specialized infrastructure. Barring a revolutionary advance in propulsion technology (which is as unlikely in the next 20 years as it is unforeseeable), SPACECAST believes that fully reusable lift systems integrated with mainstream aerospace operations offer the best hope for qualitative change in spacelift.

Problems With Reusables and General Design Goals. From basic intuition through the justification for the space shuttle to the most recent studies[14], fully reusable systems offer the greatest operational flexibility and potential cut in launch costs. Three problems continually recur: First, how to build a system that is completely reusable and has acceptable performance; second, how to justify the nonrecurring costs (infrastructure investment as well as hardware development) to get the eventual benefits of lower recurring costs; and third, how to reduce recurring costs to the point where an eventual payback can be expected. The space shuttle's problems in these areas and others have disillusioned people, but a radically different design may finally vindicate the reusable launch system approach.

The problems with fully reusable launch vehicles may have their basis in misplaced attachment to old paradigms of space systems (i.e. at least 20,000 pounds of lift capacity are needed to place useful payloads in orbit). The reason for this is twofold: first, it reflects satellite design assumptions that do not account for advances in miniaturization and modularity (i.e. what has become possible) and second, it assumes that payload size is the primary determinant of a launch system's utility (as opposed to, say, cost-per-pound of payload in orbit, or the ability to launch on extremely short notice). This drives performance to the edge of the envelope, creates tremendous development costs and dependence on immature technologies, usually fails to address operational implications sufficiently, and produces huge specialized infrastructure requirements that further drive up recurring and nonrecurring costs. These crippling problems can be overcome if designers challenge the old assumptions about space lift.

Space authorities have now acknowledged the negative relationship between trying to get the maximum number of pounds of payload onto a given rocket and cost and reliability.[15] Further, as discussed above, the vicious cycle of large satellite design and the opportunities provided by miniaturization and other advancing technologies argue in favor of smaller, standardized satellite designs.[16] Finally, military space authorities have expressed frustration with the "custom rocket" approach that comes from attempting to squeeze every last ounce of lift out of a given booster.[17] The time is ripe to design an operationally sound launch vehicle--one that utilizes existing, common infrastructure, can be maintained by well-trained high school graduates, and can be operated by well-trained non-scientist college graduates--first, then build payloads to fit it.

Development costs and dependence on immature technologies are linked to the performance issue. Because performance requirements are so high, only exotic fuels, engines, or

design concepts can possibly meet them. As a result, billions of dollars in research and development are required to validate (and sometimes invent) the enabling technologies. All too often the success or failure of a given approach cannot be determined until the system is actually built, and even a prototype incorporating many advanced technologies may be prohibitively expensive. As an alternative, SPACECAST proposes an affordable X-vehicle development program that has clear near term military relevance and traceability to an operational system.

Failure to take into account the operational implications of a launch system—not just the launch crew but the support infrastructure for such things as fueling, maintenance, logistics, or basing—has been crippling in terms of cost and the eventual utility of systems. NASP-derived and two stage (carrier vehicle and space plane) concepts seem particularly vulnerable to this shortcoming, although they still represent an improvement over the huge, archaic, expensive, inflexible and manpower-intensive procedures required for current lift systems.[18] From the start, operational and infrastructure considerations must be given top priority. Space operations must become as routine and non-exotic as air operations.

Toward a New Type of Lift System: The "Black Horse" Transatmospheric Vehicles. To address these concerns, suppose that maximum performance (in terms of specific impulse for rockets) is not necessary or even desirable. This permits consideration of noncryogenic propellants, which offer several advantages. If these propellants are sufficiently dense, a workable lift system can be designed. The British did so with the Black Arrow and Black Knight programs using 1950s technology. This is because factors such as a reduction in tankage volume (hence rocket empty weight), a decrease in engine complexity, and an improved engine thrust-to-weight ratio make up for much of the (propellant) performance loss. Figure 2 shows how propellant density affects vehicle internal volume requirements. Interestingly, one of the most attractive combinations of noncryogenic propellants is jet fuel (nominally JP-5) and hydrogen peroxide.[19]

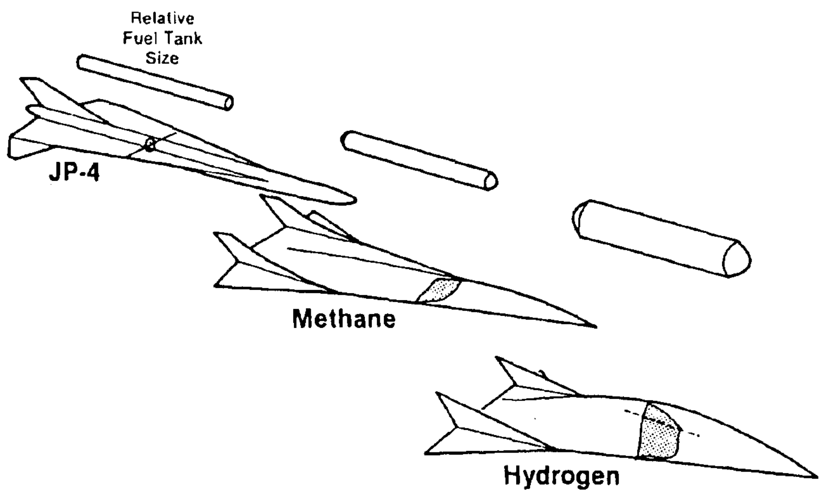


Figure 2. Notional Vehicle Cross Sections for Different Fuels[20]

The real attraction of this propellant combination is in the operational arena. The propellants are easily available (hydrogen peroxide is commonly sold for industrial uses at 70 percent purity; vendors could provide higher purities, or the commercial product could be refined on-site), storable, and pose no significant logistics problems. Rocket engines using these propellants also have excellent reliability histories, both on the Black Arrow and Black Knight programs and on the NF-104D research aircraft. The NF-104D program started such an engine (using JP-4 and H_2O_2) at least two times on every flight, experienced no rocket-engine-related emergencies during 11 years of operation, and was serviced and maintained with "essentially conventional maintenance procedures and normally trained personnel."[21] Storage and handling of high-purity H_2O_2 is not inherently dangerous, and requires primarily discipline, not extensive safety equipment.[22] The Black Arrow and NF-104D programs routinely used 85-90% pure hydrogen peroxide; there are no known chemical reasons why operations with higher purities would be any more difficult. Finally, servicing a vehicle that uses cryogenic propellants requires many more steps (and is thus much slower) than servicing a noncryogenic-fueled (such as JP-5 and H_2O_2) vehicle. Even on the DC-X SSTO demonstrator, which had ease of operations as a design goal, fully 80 percent of the preflight checklist items were cryogenics-related.[23]

If readily available and easily stored propellants are used, the only reasons why a reusable vehicle could not operate from any location would be specialized requirements for assembly/loading, launch, and landing. Although a vertical takeoff and landing system has advantages in terms of empty weight and choice of launch/landing sites (theoretically it only needs

a small pad), the SPACECAST Lift Team believes a horizontal takeoff and landing system is a better near term approach.

There are many advantages to a horizontal takeoff and landing space launch system. First, there are sufficient airfields available for any conceivable missions.[24] Second, fuel supplies and logistics infrastructure (crew equipment, admin support, ground transportation, maintenance and other ground personnel) are already located at airfields. Finally, a horizontal takeoff and landing vehicle would almost certainly be more robust. Its advantages include a larger abort envelope, the ability to land with all engines out, and greater cross-range on reentry. Further discussion of this issue can be found at Attachment B. There is a performance penalty associated this approach (hence the DC-X design), but there is also an ingenious way to compensate for it--aerial propellant transfer.[25]

True SSTO vehicles must lift all the propellant they need to reach orbit from the ground. This in turn drives the gross takeoff weight of the vehicle (including the wing and landing gear for horizontal takeoff and/or landing), hence its size and the engine and structural margins needed for safe take off and in case of a launch abort. Much of this structure is dead weight long before the vehicle leaves the atmosphere (hence staged designs). To date, two design approaches have attempted to eliminate this problem for SSTOs: NASP, which is an air breather for much of its flight, and the carrier vehicle/space plane two-stage concept. Both approaches have numerous drawbacks.[26] However, if the TAV can be launched with minimum propellants, and then *rendezvous with an aerial refueler* to load the remainder of the propellants, a different, more flexible design is possible. The choice of noncryogenic propellants is essential here, and the properties of a JP-5-hydrogen peroxide engine in particular (H_2O_2 is almost twice as dense as jet fuel, and the engine operates at a 1:7 fuel: oxidizer mix by weight) make it attractive to consider transferring the bulk of the oxidizer after takeoff.

At least initially, designers have conceived the Black Horse TAV as a manned system. Without addressing whether or not a crew is or always will be necessary, designers have planned for a crew for these reasons: A crew is essential for the initial X-vehicle development program, although that same program could test technologies that would enable later unmanned versions (unmanned aerial refueling, for example); a crew is desirable for several of the suborbital missions described below; and a crew <u>may</u> be desirable for some operations in space. If the vehicle has an austere (U-2-like) cockpit and is not designed for long-duration orbital missions (as will almost certainly be true for the X-vehicles), the effects of loss of payload weight will be minimized. The issue of whether man-rating from the beginning causes unacceptable costs is not a valid concern,

since this system is not a piece of long-range artillery (a raglan or an ICBM) converted for transport use. It is, essentially, a fast, high-flying aircraft with no greater risks to crewmembers than any other developmental system.[27] Further discussion of this issue is in Attachment C.

In summary, the Black Horse TAV is a new kind of aerospace vehicle concept. It is not a new version of the space shuttle or NASP, and explicitly contains design choices in terms of size, performance and mission profile to ensure that those experiences will not be repeated. Specifically, Black Horse is a small vehicle with low empty weight and low weight on orbit, factors that historically correspond to cost. Black Horse--at least the initial X-vehicle concept as described below--is designed around existing technologies and for full reusability (unlike Shuttle) and ruggedness at the expense of the highest possible performance. Any comparison to NASP is particularly inappropriate: aside from horizontal takeoff and landing, there is no similarity. Because of the airbreathing engine, the low density fuel and the requirement to fly hypersonically in relatively dense air, NASP required multiple technological breakthroughs in propulsion and materials. In comparison, Black Horse thermal and structural requirements are much less stringent.

The structure of the Black Horse was designed using standard aircraft practice: given the maximum propellant offload from a KC-135 tanker, an estimated structural weight (from the volume required to enclose fuel, crew, payload, etc) and assumed weights for payload, crew, thermal protection and other subsystems, a wing was designed to provide sufficient lift throughout the flight envelope. This design was then iterated to ensure internal consistency. The resulting design (see attachment G) has a relatively low structural mass fraction when compared to other orbital vehicles. This has two primary causes: first, the propellants are substantially denser than "traditional" rocket fuels, thus the enclosed volume of the vehicle and consequently the structural weight is low. Second, by transferring the bulk of the propellant once airborne, the designers have avoided the penalty of sizing the wing, landing gear and supporting structure for a fully-loaded takeoff. This technique results in a savings of 4,200 pounds for the landing gear alone[28], and essentially makes the concept possible. Critics of the concept have expressed doubts about the numbers, but others, including Burt Rutan of Scaled Composites, have no doubts about the technical feasibility of the structure. Indeed, Mr Rutan believes the structure could be made even lighter using composites, instead of aluminum as the designers assumed.[29]

Other structural issues include the design of the payload bay and the thermal protection system. Although the payload bay was not designed in detail, additional structure was assumed based on aircraft requirements for internal cargo or weapons carriage. A thermal protection

system of blanket insulating material and carbon-silica carbide (for the nose and leading edges), with a weight of 1.1 pounds per square foot, was included in the design.

The baseline design is for a vehicle weighing 48,450 pounds at takeoff (and 187,000 pounds after aerial refueling) powered by seven rocket engines. Two engines suffice for takeoff and the full refueling profile, so are optimized for lower altitude performance; the remaining five provide the additional thrust necessary for global reach or orbital insertion.[30]

The performance of the engines and fuel (JP-5 and hydrogen peroxide) was estimated using NASA standard codes and incorporating losses from geometry, finite rate chemistry, viscous drag and energy release efficiency. This results in a specific impulse of 323 seconds for the low altitude engines and 335 for the orbital insertion engines.[31] In terms of thrust to weight ratio for the engine itself, the performance is no higher than what the British were able to obtain from the Gamma engines (using kerosene and hydrogen peroxide) designed and built in the 1960's; the designers believe that this is a conservative estimate of potential performance.

The final element of the design is the payload deliverable on orbit. This depends on several factors, but as a figure of merit, the designers chose a 1,000 pound payload in a 35 degree inclined 100 nmi circular orbit (due east launch from Edwards AFB from a refueling track at 40,000 feet and .85 Mach). This assumes, of course, that the TAV also goes to orbit; flying a suborbital trajectory allows a significantly greater payload (6,600 pounds) to be placed in orbit, even after the weight of an upper stage (a 4,765 pound STAR 48V) is subtracted. If weapons or cargo delivery is the goal, 5,000 to 10,000 pounds could be delivered on a suborbital trajectory to almost any point on the globe using the baseline design.[32] The designers believe that all these numbers can be improved through better engines, lighter dry weight, potential fuel additives, and finally, by increasing the size of the vehicle (if so desired for an eventual operational system). These alternatives are discussed in more detail later in the paper.

Design Requirements for Weapons Delivery. There are several alternatives for delivering weapons, including the TAV described in preceding sections, ICBMs, satellite basing, and intercontinental cannons. The SPACECAST lift team believes operational flexibility greatly favors the TAV approach. A more detailed discussion of this is in Attachment D.

An appropriately configured version of the TAV can perform both ground and space force application missions with near term technologies. Some key characteristics of the air-refuelable rocket-powered TAV that are particularly relevant are the ability to operate as flexibly and

responsively as an aircraft (with similar operations, maintenance, and logistics infrastructures), its inherently low observable nature from most aspects (no inlets, blended surfaces), and its ability to conduct manned missions. The vehicle has the ability to exploit the advantages of space basing (low reaction times and high energy states) with far greater operational flexibility and additional defensive capabilities to survive the future threat. Although the ideas presented in this section were arrived at independently, this concept is not new. Several other studies recommended similar vehicles.[33]

The system must have specific characteristics to accomplish the force application mission. First, the vehicle must be able to launch from a quick reaction alert status. This enables short response times critical to any future weapon system's success. The Black Horse TAV is capable of fulfilling this requirement in large part because of its use of noncryogenic fuels.

Second, the vehicle must be designed to incorporate modular weapons systems sized to fit the payload bay of the TAV. This concept allows use of the vehicle for a variety of military missions from force enhancement through force application, thereby increasing cost effectiveness. The TAV should be hard-wired to provide necessary infrastructure requirements (for example, basic power and communication links) to the module while the module reports fault/degradation information to the operator or controlling computer on the TAV. Note that these interfaces would not be significantly different from those required to launch a satellite. The largest part of the necessary weapons delivery infrastructure should be designed, as much as possible, into the clip-in module and not the carrier vehicle.

The idea of weapon modules serves several purposes. With this approach, the vehicle is able to accomplish force enhancement missions until required for weapons delivery; in other words, it is rapidly reconfigurable for different missions. In addition, the weapons modules can be preloaded with "wooden rounds," stored until needed and then quickly loaded on the vehicle. Maintenance or upgrades can be accomplished on the ground-based weapons ensuring maximum reliability and capability. Finally, the module concept offers quick reloads, facilitating rapid turn-times and therefore sustainability. By analogy with current dispensing systems, the deliverable payload should be approximately 75 percent of the vehicle's total payload capacity.[34]

Third, for survivability and maximum offensive potential, the vehicle must have global reach from a suborbital flight path. Global reach provides operational flexibility while allowing the vehicle to launch and recover from secure areas. The suborbital requirement contributes to self-protection tactics and is explained more fully later. Additionally, since the suborbital flight

path requires less propellant than orbital insertion, greater weapon loads than for orbital payloads should result. Since weapons will generally be more dense than spacecraft, this should mean that an efficient multipurpose payload bay design is possible. Again, the Black Horse TAV satisfies this requirement.

Fourth, the TAV must allow rapid turn-around to follow-on missions. This maintains the initiative and offensive advantage for the CINC and allows rapid follow-on targeting. It is unrealistic to assume the military will have enough vehicles to engage all possible target sets with a single mass launch. Actual requirements for turn-around times will depend on the number of vehicles, the payload capacity for each, the number of aimpoints, and the threat. Any attempt to fix a hard number in relation to these requirements requires some detailed operations analysis, but a 12-hour cycle rate seems a reasonable minimum design criterion. The TAV and associated aircrew-to-airframe ratios should meet this minimum requirement.

Fifth, the system should maximize the use of existing military infrastructure. This requirement is levied to allow launch and recovery from the widest possible number of bases. This provides some measure of survivability through dispersion and mobility. The TAV provides a limited solution to this requirement and is restricted only by airfield length/capacity and refueling support. Attachment B contains further discussion of the horizontal versus vertical takeoff and landing issues.

Sixth, the issue of designing this vehicle for humans is important only in the near term. Technology has not progressed to the state where a computer can replace humans in all operations, specifically those in unpredictable environments or in degraded equipment modes. The SPACECAST lift team recommends designing early vehicles for human operators. While this will result in higher weight and lower G capability (the latter is probably not an issue for typical mission profiles), a human operator allows for rapid, autonomous (in accordance with the commander's intent) decision making, while facing the technologically advanced threat of the twenty-first century. When the data base is developed and hardware and software technology is sufficiently proven, human operators theoretically could be removed from the vehicle. Virtual reality is not a solution in the interim. Communications links are vulnerable to an advanced enemy and could be jammed or exploited. Taken together, these all argue that human pilots and human systems operators will continue to provide significant advantages, at least in the near term.

Finally, payload size may be a limiting factor in some specific employment scenarios. SPACECAST believes that the Black Horse TAV concept offers sufficient payload potential to

perform a number of militarily useful missions. As mentioned earlier, a TAV capable of putting itself and 1,000 pounds of payload on orbit can deliver significantly more payload on a suborbital trajectory; further, there is significant growth potential in the basic design (sizing the vehicle around the fuel offload from a tanker larger than the KC-135, for example) which would lead to larger deliverable payloads.

Weapons Options. Three classes of weapons are appropriate for this vehicle: kinetic energy weapons, high explosive weapons, and directed energy weapons. In general, all weapons should be palletized or containerized for maximum flexibility in switching missions and to allow incremental upgrades and maintenance while the weapons are in storage. The Force Application white papers discusses these weapon types in more detail. Some general thoughts are in Attachment E.

In summary, a TAV capable of employing modular military payloads provides the United States a sustained counterforce capability for use against a wide variety of targets defended by increasingly capable future threats.

On-Orbit Operations Vehicles

As mentioned earlier, the ability to maneuver transfer or maneuver payloads on orbit provides enhancements to any lift system. This section addresses some general issues, but does not assume the use of any specific vehicle design (for example, the NASA Marshall Space Flight Center STV) or associated operations concepts. In other words, SPACECAST is not advocating use of on-orbit operations vehicles to be tied to any specific satellite architecture. However, the Lift team does recognize that tradeoffs (i.e. is it better to repair/service/upgrade a particular satellite or replace it) will be an integral part of any decision to pursue on-orbit operations vehicles.

Two key issues are important to this concept: the utility of reusable on-orbit transportation systems and the utility of on-orbit satellite servicing and repair. With regard to transportation systems, a 1989 study by the Air Force Systems Command (now Air Force Materiel Command) Directorate of Aerospace Studies (DAS) identified two basic vehicle configurations or capabilities: an orbit transfer vehicle (OTV) for moving things from low earth orbit (LEO) to higher orbits, and an orbital maneuvering vehicle (OMV) for moving things around within a designated orbit and docking with and servicing satellites. This architecture is superior to the current approach (expendable upper stages and/or propulsion systems integral to the

spacecraft bus) for several reasons. Expendable upper stages are, by definition and design, thrown away after use and become "space junk." More importantly, however, while their unit costs are less than those of reusable vehicles, reusable systems are "generally less expensive on a per mission basis" over their usable lifetime.[35]

The DAS study also addressed the issue of whether or not it is more advantageous to use an on-orbit transportation capability to service and/or repair satellites on orbit, or to continue fielding expendable satellites. As expected, there is no clear answer. On the one hand, the authors conclude that, "it is reasonable to believe that there will be future circumstances which offer cost advantages to repairable satellites."[36] On the other hand, the analysis was sensitive enough to the estimated characteristics of future satellites (e.g., mission duration, mass, cost, subsystem reliability, and launch costs) that the results were not conclusive for all satellites in all orbits. In general, satellite repair becomes more attractive as constellation size and satellite mass, cost, and mission duration increase, and as launch costs and satellite reliability decrease. It is much more attractive from a cost standpoint if satellites use modular, standardized/common subsystems. The utility of reusable on-orbit transportation systems for satellite servicing and repair in the 2020 timeframe depends heavily on the types and quantities of satellites in orbit at that time, as well as on the capabilities and costs of US launch systems. Given this paper's assumptions of increasingly capable small packages and the ability to put them responsively on orbit, it is not at all clear that repair or resupply of existing satellites are attractive missions. On the other hand, if smaller but more cost-effective launch vehicles make on-orbit assembly and fueling of larger satellites desirable, many of the technologies discussed below will be needed. Ironically, it is the present large satellite paradigm and its associated high cost-per-pound to orbit that prevents testing the on-orbit repair concept.

Operations Concept

Basic Transatmospheric Vehicle Operations and Orbital Lift. The TAV would be readied for flight at an aerospace base different only from an airbase by the H_2O_2 storage and first level maintenance equipment, all of which could be deployed; fueled with 100 percent of its JP-5 and approximately 7 percent of its H_2O_2 capacity; loaded with its payload; taxi and take off; rendezvous with a tanker and load the entire tanker's capacity of H_2O_2; turn to the correct heading; and depart for orbit. From push-back to orbit would take less than an hour.

Once its orbital mission was completed, the TAV would deorbit and return to its own or any other suitable base; again, a very short process. A suborbital mission would be similar, and there would probably be no need to refuel before returning to base. Turn-around time is

somewhat speculative at this point (the X-vehicle program would answer this), but a preliminary look at the technologies (rocket engine, thermal protection, etc.) suggests it will be a matter of hours or no more than days at worst; unlike the space shuttle, the TAV would be designed so as not to require extensive refurbishment between flights. Two technical areas are the key to the ability to "turn" the TAV quickly: thermal protection and engines. For the former, the combination of the aerothermal environment (less stressing even than for the space shuttle due to Black Horse's low wing loading and deceleration high in the atmosphere) and advances in materials since the space shuttle was designed should make the design of a fully reusable system possible. For the engines, the AR-2 used on the NF-104D provides a baseline: it routinely operated with two hours firing time (and numerous restarts) between overhauls[37]; the Black Horse designers believe that an improved design could do better. Although one of the purposes of an X-program would be to test the limits of reusability of a TAV, SPACECAST does not believe there are any showstoppers here.

This concept will provide vastly increased flexibility and responsiveness in launching spacecraft and performing suborbital missions, tremendously reduced operations and logistics infrastructure compared to other lift concepts, increased reliability, suitability for manned flight, and significantly reduced cost of space launch. It also builds on a current military aviation operational strength of aerial refueling, which has been done hundreds of times a day, versus airborne separation of large manned vehicles, which has been done a few hundred times in history in developing a new space launch capability. A squadron of eight Black Horse vehicles, even flying only once per week each, would provide access to space <u>hundreds</u> of times per year, making space operations truly routine. A summary of developmental and operational considerations for Black Horse TAVs is in Attachment F.

<u>A Threat-based System</u>. Future threats to the United States will possess far greater capability to impact offensive operations than current threats. Several types of threats are possible: hostile threat satellites, ground and space-based directed energy weapons, intercontinental ballistic missiles, and third world nuclear weapons and other weapons of mass destruction. An armed TAV could negate future threats through a combination of countermeasures, tactics, and survivable basing.

First, the construction of the vehicle should include as many low observable techniques as possible. While today's low observable technologies will gradually lose their utility, they will force adversaries to confine defensive systems to particular (and therefore predictable) techniques.

They have the further benefit of reducing the detection envelope of enemy acquisition systems and therefore making the adversary's targeting problem more difficult.

Second, on-board active defensive systems are possible with this system. By using a suborbital trajectory during the attack profile, a TAV may use such disposables as chaff, flares, towed decoys, and active defensive munitions to defeat threat weapon systems without contributing to hazardous space junk. The design of the operational TAV could also accommodate modular Electronic Counter Measure (ECM) systems, weight and power budgets permitting.

Third, the TAV concept permits surprise. Even if an adversary has spies operating in the vicinity of airfields, if commercial media satellites detect operations in progress, or if the enemy detects unusual launch activity, the specific aimpoints, axes of attack, and timing of the attack are less easily predictable. Launch to a single suborbital weapons delivery pass followed by reentry and landing compresses the time the adversary has to respond--especially an adversary without either space surveillance capability or intercontinental launch detection. The enemy has minutes to observe the mission, assess intentions, make the appropriate decision, get the defensive capabilities in place, and complete the intercept. Multiple, simultaneous, inbound trajectories compound surprise and the next two effects.

Fourth, the inherent flexibility of a TAV enhances unpredictability. Again, the single suborbital pass serves as an example. Since the vehicle starts from ground alert, the enemy cannot predict the mission's time over target. The capability of the vehicle to establish a variety of suborbital trajectories, as well as approaching the target from differing orbital planes, also confounds the adversary's predictive ability and may negate many of his defensive systems.

Fifth, a squadron of TAVs translates into mass. The United States will more than likely have a small fleet of these reusable vehicles. The ability to mass several vehicles from single suborbital passes at the time and place chosen by the CINC, allows the commander to overwhelm the enemy's defensive systems as well as concentrate the appropriate amount of firepower to achieve required effects. In the absence of great numbers of vehicles, the same mass effect is maintained through the ability of each vehicle to deliver a large number of weapons.

Sixth, standoff. This assumes an appropriate family of weapons with sufficient crosstrack (to the sides of the delivery vehicle trajectory) capability. With these, the vehicle can release its payload outside the range of many possible threat systems.

Seventh, mutual support. Several vehicles working in concert can use advanced countermeasures as well as suppress threats for each other. The clip-in module for one vehicle, for example, might be a countermeasures suite. The clip-in modules for other vehicles in a flight would be weapons.

Finally, TAVs can easily be based in a dispersed fashion. While threat systems will surely have the ability to find and target aimpoints in the United States by the year 2020, their capabilities can be reduced through dispersion of the TAVs to a wide number of bases, through mobile operations, and through good deception plans. (An enemy's problem would be compounded if a large number of commercial TAVs also exist.) Any attempt to force this system to consolidate operations at a single fixed location is unnecessary and should be resisted as it obviously provides the adversary a fixed, high-value target. Logistics concerns can be adequately addressed by designing a vehicle that shares existing aircraft infrastructure to the maximum extent possible.

In summary, the ability of the TAV to accomplish its weapons delivery mission from a single suborbital pass, while using both passive and active countermeasures, compresses the adversary's decision loop and results in increased survivability. The addition of low-profile basing complicates the threat's targeting problem and ensures fewer assets are risked to the adversary's efforts during strategic attack. This combination results in a survivable system able to fight in the high threat environment of the 21st century.

<u>On-Orbit Operations</u>. To a large extent, the type of operations performed on orbit will be determined by the capabilities that new vehicles provide, whether OTV, OMV, or TAV. Orbit transfer vehicles could reduce the need for upper stages on launch systems with a corresponding increase in the amount of payload delivered to orbit. Maneuvering vehicles could provide some repositioning or on-orbit shuttle capabilities, a function that would help make orbital operating bases (space stations) functional. Both of these vehicles will facilitate on-orbit maintenance and upgrades to extend satellite lifetimes and combat technological obsolescence.

Even the TAV has implications for orbital operations. Besides capturing satellites and returning them to earth, the TAV may prove the best way to change a satellite's inclination. Assuming it is not easier to launch a new satellite to the relevant orbit, the TAV could go to orbit without cargo (to conserve fuel), capture a satellite, reenter and perform an aerodynamic maneuver to align itself with the new orbit (perhaps in extreme cases even refueling again), then

return the satellite to space. Although the Black Horse studies to date have not included calculations of the fuel required for on-orbit rendezvous, this is a potential mission if the vehicle does not go to orbit fully loaded; unlike shuttle operations, launching an empty vehicle would not be a cost-prohibitive operation.

Links to Other SPACECAST Areas

The concept of the TAV connects many of the SPACECAST white papers. The logistics area of space lift with a militarily capable TAV is now linked to the white paper on a Global View architecture. This combination uses the proposed architecture to identify and pass coordinates of critical targets to the TAV prior to its weapons release point, cutting the time from initial target detection to destruction to an absolute minimum. This ensures that the TAV uses the most effective targeting intelligence to gain the greatest possible strategic effects.

The Force Application paper discusses various weapons types and their suitability. The TAV offers a platform for their use with significant military advantages over other techniques such as satellite basing. System architectures mentioned are compatible with the weapons delivery vehicle concept. Finally, the Offensive Counterspace area benefits from a TAV-based weapons system which could allow use of directed energy weapons without the requirement of building, deploying, operating, and defending an orbiting "battlestar."

Other linkages include the ability of the vehicles described in this paper to support the "motherboard" satellite concept described in the Space Modular Systems white paper, and the utility of a Space Traffic Control system in accommodating both the TAVs as well as increased on-orbit activity. Finally, many of the concepts in SPACECAST depend heavily on improving and reducing the cost of access to space--the heart of the Black Horse TAV concept.

Potential Technologies

Transatmospheric Vehicles

Although a working TAV in the form of an X-vehicle can be built with existing technologies (see Attachment G), there are several areas where improved technologies and/or supporting capabilities will enhance performance.

o Structures. The initial aerial refueled space plane feasibility study, no formal title,[38] concluded that using standard fighter aircraft design criteria and aluminum structures, an F-16-sized X-vehicle TAV could place itself, a crew and 1,000 pounds of payload into orbit. However, further analysis of structural requirements and application of modern design techniques and materials could significantly reduce structural weight. As mentioned earlier, Mr Burt Rutan of Scaled Composites believes this is within current design and fabrication capabilities. Since Black Horse is a single stage to orbit vehicle, every pound of dry weight saved is an extra pound of payload.

o Engines. The same study baselined an engine no more sophisticated or efficient than the one used by the Black Arrow/Black Knight program (1950s technology).[39] A modest development program could certainly improve on this level of performance (efficiency, thrust to weight ratio) while improving reliability and maintainability. For a further step, a hybrid engine such as a ducted rocket[40] (admittedly a separate development program) could offer both a performance increase and reduced noise; both potentially critical factors for widespread commercial use of TAVs.

o Propellants. Although the intent of the program is to stay away from exotic or hazardous materials, there are options to increase specific impulse without sacrificing operability. Some possibilities are fuel additives such as quadricyclene, denser hydrocarbons (JP-8 or 10 vice JP-5) or, in the far term, high energy density substances such as metastable fuels (discussed in the Unconventional Lift paper). As long as the fuel continues to meet operability and logistics concerns, this is an area with tremendous potential payoff. An increase of one second in specific impulse would increase payload on orbit by 128 pounds for the initial Black Horse design.[41]

o Thermal protection system. The feasibility study referenced above baselined DuraTABI (Durable Tailored Advanced Blanket Insulation) material which weighs 1.1 pounds per square foot for area ("acreage") coverage and carbon-silica carbide (C/SiC) for the nose and wing, strake and rudder leading edges. Detailed aerothermodynamic reentry calculations may indicate a less stringent requirement for thermal protection than was assumed in the initial design, possibly allowing even an all-metal skin (Rene 41 or Iconel 617). On the other hand, retaining excess thermal protection, perhaps by applying more advanced thermal protection systems, could give the vehicle a larger reentry envelope and even more operational flexibility.

o Refueling vehicle. Designers sized the TAV around the maximum amount of propellant that a single KC-135Q could transfer. These aircraft are in the inventory and already have

separate aircraft fuel and off-loadable propellant tanks. Thus they would require minimum modification. The availability of a modified KC-10 or large commercial aircraft derivative to offload H_2O_2 would greatly increase the potential size and payload of the TAV without significantly changing (except perhaps to reduce) the cost-per-pound to orbit. Although this is more a programmatic than a technical issue, there are potential areas for investment in higher capacity pumps and perhaps a dual-tube boom refueling system to transfer both fuel and oxidizer at once. Attachment G, which outlines a multielement X-vehicle program, addresses these and several other technology issues.

On-orbit Operations Vehicles

As mentioned earlier, on-orbit operations vehicles complement most lift concepts. These vehicles have distinct technology development, demonstration and validation needs, however; these are outlined below.

Technologies required to implement on-orbit operations architecture include high efficiency, reusable space propulsion systems. Cost, performance, and operational utility analyses are needed to select from among the various potential technologies. Candidates include conventional chemical, electric, nuclear, and solar-thermal propulsion systems. Issues to be addressed would include: power sources for electric propulsion concepts; radiation shielding, high-temperature materials, launch safety, and waste disposal for nuclear propulsion concepts; solar concentrator fabrication and high-temperature materials for solar-thermal propulsion concepts; and long-life performance/reliability demonstrations for all concepts.

The on-orbit operations vehicles will require robotics for docking, grasping, repair, and resupply operations and/or telepresence/virtual reality/artificial intelligence technologies in some combination for on-orbit operations. Planners need analyses to determine the extent to which humans must participate in repair/servicing operations. Considering the technologies expected to be available in 2020, planners need to know what tasks can be done only by human beings, what tasks can be done remotely with humans in-the-loop, and what tasks can be done autonomously. Artificial intelligence technologies could reduce the requirement for human-in-the-loop operations in circumstances where this would be difficult or present technical challenges. Again, further analysis is required.

Spacecraft design would have to change significantly to obtain maximum utility from the TAV concept. Docking operations would require some degree of spacecraft bus standardization.

Refueling operations would require propellant feed system standardization. Such design approaches as standard spacecraft buses and standard, modular, miniaturized subsystems and interfaces would facilitate repair/upgrade operation. External structures like solar arrays and antennae might have to fold to withstand the accelerations associated with high impulse spacecraft maneuvers or to stow the spacecraft in the bay of a TAV for redeployment. It is important to note that many of these changes will happen with or without the development of on-orbit servicing. They are driven by the need to reduce the costs and timelines associated with the earth-to-orbit segment of the transportation system.

OTVs may need supporting "bases" in certain critical locations. For transportation to high-altitude, low-inclination orbits, unmanned coinclination platforms in LEO would serve as cargo transfer and jumping off points for OTVs. Orbits containing large numbers of higher-cost satellites or fewer extremely expensive satellites would require co-orbital unmanned platforms where OTVs could transfer payloads to OMVs for final orbit insertion or docking/repair.[42]

Near Term Technologies and Operational Exploitation Opportunities

Transatmospheric Vehicle

Designers can use existing and proven technologies--aluminum structure, DuraTABI thermal protection--to develop and fly an X-vehicle to demonstrate the feasibility and operational utility of the Black Horse. As an interim step (discussed in more detail in Attachment G), existing AR-2 engines could be used to fly the vehicle through all of its atmospheric flight profile, testing handling, formation flying, refueling and suborbital trajectories, while a concurrent engine development program produces the higher performance engines needed to reach orbit. The basic concept is for a crewed vehicle approximately the size of an F-16 but with only 70 percent of its dry weight that could take off from and land on virtually any runway, load the bulk of its propellant (all oxidizer) from a KC-135Q (or T) tanker at approximately 40,000 feet and Mach 0.85,[43] and then carry out an orbital or suborbital flight. An experimental program could allow testing of the TAV as the US has tested aircraft for decades, with a gradual expansion of the performance envelope to meet the necessary objectives.[44] Some other characteristics of the program are in at Attachment G.

The primary areas for design and development are the vehicle aerodynamic configuration, higher performance rocket engines, and the vehicle structure. The WJ Schafer and Associates and Conceptual Research Corporation study[45] indicates there are no technological roadblocks in this

area, and a vehicle could be designed and tested with existing technologies, although there is room for improvement using advanced materials.

Areas that require some careful design work but no technological breakthroughs are thermal protection, the need to cycle landing gear through the thermal protective surface, and the use of structural composites. It therefore appears that an X-vehicle program could proceed *with existing technologies.*

o Cost. Although not the single driving issue in this study, several comparative estimates of a two-TAV, 100 flight (including orbital) X-vehicle program suggested that the military could conduct such a program for a reasonable amount of money. Using actual X-29 and X-31 cost data, the Question Mark 2 TAV X-program would cost about $78 million (M). A Lockheed Skunkworks program cost model yielded $96 M. The RAND Corporation Development and Procurement Costs of Aircraft (DAPCA) IV model gave a total program cost of $118M. Finally, a cost estimate by an Aerospace Corporation analyst came up with $120M.[46] Although these are rough estimates and a vehicle of this type has never been built before, the fact that differing methodologies independently came up with similar numbers is somewhat encouraging.

o Operational Costs. Initial estimates, using a cost model based on SR-71 actual expense data, suggest that a Black Horse type vehicle could place payloads into low earth orbit at a cost of less than $1,000 per pound (the model yields costs between $50 and $500 per pound depending on assumptions) with a per-sortie cost of around $260,000 and an annual operating budget for an eight TAV unit, with support, of approximately $100M. This model may be particularly appropriate because the operations of an air-refuelable TAV and the SR-71 would be similar in several ways, not the least of which is using the same tanker. The model includes and is sensitive to overhead costs (assumed to be the same as for the SR-71), number of vehicles and sorties, payload (assumed to be 1,000 pounds), and fuel costs. A key point to emphasize is that this system is not "cheap" to operate relative to most aircraft; in fact the numbers are comparable to SR-71 operating costs. The cost-per-pound to orbit, however, even under fairly pessimistic assumptions (smallest payload, relatively few flights, high nonflying operations cost), is still quite low compared to other launch systems. Perhaps this shows just how expensive our current space operations really are (at $10,000 per pound to orbit and up), and how large the potential for improving that figure is with reusable launch vehicles. Cost-sensitive basing schemes and logistics concepts such as the USAF's "Rivet Workforce" which consolidate maintenance skills could further reduce recurring operations and maintenance costs. The assumptions and a comparison of costs using different assumptions are at Attachment H.

On-Orbit Operations

There are several near-term programs that would expand our ability to provide on-orbit services. These include the Space Surveillance Tracking and Repositioning (SSTAR) experiment (formerly called the Electric Insertion Transfer Experiment, or ELITE), an Air Force-TRW cooperative research and development agreement, a potential flight test of the ex-Soviet TOPAZ nuclear reactor, and the Space Nuclear Thermal Propulsion program. These deal primarily with propulsion systems, but particularly in the case of SSTAR, also with supporting technologies such as navigation, autonomous operation, and potential mission-oriented payloads. Unfortunately, all of these programs have suffered funding setbacks and are on hold or in danger of cancellation.

Commercial Opportunities

Cheap, reliable transport to, from, and through space offers innumerable possibilities.[47] It is the enabler for everything anyone does in the future in space. All of the technologies and techniques described above have potential commercial application, but a prescription of their use is beyond the scope of this study. Instead, this paper highlights some of the opportunities they may create, and why a robust commercial space market is ultimately essential for government use of space.

o Implications for markets. Cheap spacelift is a market enabler that will open up the use of space for things not currently practical or even anticipated. Some obvious possibilities include the extremely rapid delivery of people and cargo from one point on the earth to another, while the ability to carry passengers safely and at a reasonable cost could open a new market for space tourism. Availability of a technology (or technologies) that enables the economical use of space will in turn spur development of a true commercial market for all things related to space flight and operations. This will eventually drive the real cost of access to and operations in space down even further as jet transport has done in the commercial aviation market.

o Implications for US manufacturers. US launch vehicle manufacturers, if they pursue innovative technologies with true market-creating potential, could find themselves in a globally dominant position, as the US aircraft industry did following the introduction of the Boeing 707 and the DC-8. Dramatic expansion of the market for space transport, which will not happen without dramatic reductions in the cost of space access, is also absolutely necessary if the US launch industry is to remain commercially viable. The alternative can be seen in the current US

shipbuilding industry. As an increasingly inefficient and shrinking US capability, it is unable to compete with low-cost and/or subsidized foreign producers and stays alive only because of government subsidies.

Government support in the initial stage of development is vital. The market for space is not large enough to drive the kind of productive and creative explosion in space-related hardware that has occurred in electronics, for example. The main prerequisite for this market is missing--rapid, reliable, affordable spacelift. Government and the military, whose performance requirements for launch on demand are the most stressing now, must take the lead in this area and produce the technological/operational breakthrough that will enable expanded future exploitation of space and the development of a large market to unleash the powers of commercial development. Industry cannot and will not make the investments needed for such breakthroughs on its own. They face a similar market to that for air transport prior to the DC-3, while development of a TAV will require an effort like the effort to produce the first jet transports. Development of jet transports would not have been possible without government investment in jet engine technology and large aircraft (B-47, B-52), despite an already fairly large air transport market.

Summary

The core concept of this paper is the Black Horse TAV. The initial reaction of most people to the concept is, "It sounds great, but if it would really work, why hasn't anyone thought of it before?" There is no simple answer to this question. The United States did flirt with transatmospheric vehicles in research and X-vehicle programs, but decided in favor of expendable boosters because of a combination of materials limitations, engine performance requirements and other technical factors, coinciding with rapidly increasing satellite weights. It seemed that only large boosters could put the required payloads in orbit. The rocket community discarded noncryogenic propellants for similar reasons. The rocket equation dictates that noncryogen-fueled vehicles have a propellant mass fraction of about 95 percent; cryogens reduce this to about 90 percent. Since all the structure as well as the payload must fit in the remainder, vehicles fueled with noncryogens did not seem able to orbit useful payloads.

Since then, however, much has changed. Miniaturization and other technologies now allow smaller satellites to do more than they once could, while large, complex systems have become increasingly unaffordable. In other words, it is now possible to get away from the tyranny of the payload and think about designing a launch vehicle for operability and even cost

first, then building satellites to fit it. In turn, by assuming a reduced payload requirement; adding 20 years of additional knowledge in materials science, aerospace vehicle structural design, and lifting body research; and by recognizing that the greater density of noncryogenic fuels compensates somewhat for their reduced performance, the outline of a TAV concept begins to emerge. The final key element is the aerial propellant transfer.[48] Putting air refueling together with the other elements--in many ways a classic example of what John Boyd calls "destructive-creative" thinking[49] --led to the Black Horse concept.

Black Horse vehicles have the potential to revolutionize the way the military (and perhaps eventually the commercial world) uses and even thinks of space. They are true aerospace vehicles, with tremendous operational implications. A first cut analysis indicates that not only is the concept feasible, but that it can be done with no new technologies. The time is now to perform a more rigorous and detailed design, then to press ahead with a Question Mark 2 X-vehicle program to validate the system.

Attachment A

Launch System Comparison

Responsiveness (time from request for launch to orbit)

- DC-X SSTO: good; deployment (if required) and fueling time major constraint
- Black Horse: excellent; could sit alert
- Pegasus: good-excellent given alert-type arrangement
- Taurus: poor-good depending on whether system is deployed
- Sea Launch: poor-good; could require significant time to get into position
- Gun Launch: excellent

Flexibility

- Select any orbital inclination
    DC-X SSTO: limited by launch sites, available Δv
    Black Horse: unlimited access; some payload decrease to high inclinations
    Pegasus: unlimited access; some payload decrease to high inclinations
    Taurus: limited by launch sites, available Δv
    Sea Launch: unlimited access; some payload decrease to high inclinations
    Gun Launch: severely limited by number of launchers

- Interface to multiple payload types (largely payload design dependent)
    DC-X SSTO: excellent
    Black Horse: excellent
    Pegasus: good-excellent
    Taurus: good; somewhat rough ride
    Sea Launch: good
    Gun Launch: severe payload design constraints

- Ability to carry out other missions (suborbital, retrieval, space control, man in space)
    DC-X SSTO: excellent; flexible payload capabilities; reusable
    Black Horse: excellent; flexible payload capabilities; reusable
    Pegasus: fair-poor; limited payload types; expendable
    Taurus: fair; limited payload types, rough ride; expendable
    Sea Launch: fair-poor; limited payload types; expendable
    Gun Launch: poor; substantial payload design constraints; one way missions

- Surge capability
    DC-X SSTO: design dependent; to be determined
    Black Horse: design-dependent; should have SR-71-like capabilities
    Pegasus: limited to vehicles in inventory

Taurus: limited to vehicles in inventory
Sea Launch: limited to vehicles in inventory
Gun Launch: limited only by number of payloads and power

Soft Abort Capability

- DC-X SSTO: limited; single or multiple engine failure could cause loss of control
- Black Horse: excellent; engines-out landing capable
- Pegasus: none; destructive abort only
- Taurus: none; destructive abort only
- Sea Launch: none; destructive abort only
- Gun Launch: none; destructive abort only

Resiliency (return to operations following an aborted launch)

- DC-X SSTO: fair; better than most rockets if failure is not engine-related
- Black Horse: good; comparable to current aircraft operations
- Pegasus: fair; heavily dependent on knowledge of failure (no recovery)
- Taurus: fair; heavily dependent on knowledge of failure (no recovery)
- Sea Launch: fair; heavily dependent on knowledge of failure (no recovery)
- Gun Launch: good unless gun is badly damaged/destroyed

Logistics

- Requirement for unique/special infrastructure
  DC-X SSTO: fair; design will help, but some new facilities and equipment needed
  Black Horse: good; some infrastructure, but much extant and common with aircraft
  Pegasus: fair; needs carrier aircraft, stacking areas, range control
  Taurus: fair; needs deployment equipment, range control
  Sea Launch: fair; needs launch platform operations and maintenance
  Gun Launch: poor; massive, highly specialized new infrastructure

- Consumables/fuel: storage and loading
  DC-X SSTO: fair, cryogenic fuels, but designed for easy handling
  Black Horse: excellent; noncryogenic, readily available
  Pegasus: excellent: solid fuel requires no handling but must be inspected
  Taurus: excellent: solid fuel requires no handling but must be inspected
  Sea Launch: excellent: solid fuel requires no handling but must be inspected
  Gun Launch: depends on power source

- Maintenance issues
  DC-X SSTO: designed for relatively straightforward maintenance
  Black Horse: could be designed to best current aircraft practice; good engines

Pegasus: not applicable; expendable
Taurus: not applicable; expendable
Sea Launch: not applicable; expendable
Gun Launch: specialized facility maintenance needed

Reliability

- DC-X SSTO: to be determined
- Black Horse: to be determined; should be good for engines at least
- Pegasus: fair; similar to other expendable rockets
- Taurus: fair; similar to other expendable rockets
- Sea Launch: fair; similar to other expendable rockets
- Gun Launch: unknown

Ease of Operations

- Range requirements/restrictions
    DC-X SSTO: slightly better than expendable staged rockets
    Black Horse: similar to aircraft operations; possibly some noise limitations
    Pegasus: similar to other expendable rockets
    Taurus: similar to other expendable rockets
    Sea Launch: similar to other expendable rockets
    Gun Launch: unknown

- Command and control
    DC-X SSTO: similar to current range operations
    Black Horse: like aircraft
    Pegasus: similar to current range operations
    Taurus: similar to current range operations
    Sea Launch: similar to current SLBM operations
    Gun Launch: like long-range artillery

- Launch crew requirements
    DC-X SSTO: excellent; designed for minimal manning and training
    Black Horse: good; similar to aircraft operations
    Pegasus: limited but highly skilled manning
    Taurus: limited but highly skilled manning
    Sea Launch: somewhat launch platform dependent
    Gun Launch: limited but highly skilled manning

Environmental Friendliness

- DC-X SSTO: Excellent
- Black Horse: Good to excellent; combustion cleaner, more complete than jet aircraft
- Pegasus: Poor: expendable, solid rocket exhaust
- Taurus: Poor: expendable, solid rocket exhaust
- Sea Launch: Poor: expendable, solid rocket exhaust
- Gun Launch: Fair to excellent depending on power source

Cost-per-Pound to Orbit

- Recurring
  - DC-X SSTO: good to excellent; somewhat speculative at this point
  - Black Horse: excellent; based on SR-71 operations model
  - Pegasus: poor; small expendables are the most expensive per pound
  - Taurus: poor; small expendables are the most expensive per pound
  - Sea Launch: poor unless only surplus equipment used
  - Gun Launch: excellent

- Nonrecurring (including development and test)
  - DC-X SSTO: fair; multiple prototype development needed
  - Black Horse: good for X-program; vehicles could be designed to cost
  - Pegasus: sunk cost; only future upgrade money required
  - Taurus: sunk cost; only future upgrade money required
  - Sea Launch: sunk cost except for platform modifications
  - Gun Launch: poor; significant facility development needed

- Confidence in estimate
  - DC-X SSTO: largely speculative
  - Black Horse: credible but requiring proof
  - Pegasus: certain
  - Taurus: certain
  - Sea Launch: fairly well known
  - Gun Launch: largely speculative

Attachment B

Horizontal Versus Vertical Launch and Landing

Characteristics of Horizontal Systems

Horizontal takeoff and landing vehicles require wings or lifting surfaces to provide necessary lift and control throughout portions of the flight profile. Additionally, horizontal takeoff and landing requires landing gear and appropriately stressed airfields long enough for takeoff and landing. This fixed infrastructure is vulnerable to attack and is a disadvantage of horizontal launch and landing systems, including conventional aircraft. The degree to which this is a problem, however, depends heavily on the assumptions about a system's use. In the case of a transatmospheric vehicle with the ability to achieve orbit, there is little if any requirement for forward basing. If basing is primarily in CONUS, a potential enemy who could target every suitable airfield would be able to target almost any basing infrastructure.

If a vehicle can achieve short takeoff ground rolls similar to those of fighter aircraft, a horizontally launched vehicle could operate out of present-day military or civil airfields. However, landing rolls may be a different matter. Such a vehicle may require a NATO standard fighter runway of 8500 feet.

Although horizontal takeoff and landing may limit the available operations sites to airfields, wings/lifting surfaces offer advantages in vehicle maneuverability (greater cross-range capability on reentry, for example). Also, alternate landing sites may be available throughout the mission profile for aborts or in cases where the intended landing site is not available due to weather or battle damage.

An additional element of operational flexibility concerns weather. A horizontal takeoff system can operate under the same weather conditions as an aircraft. Vertical systems like current rockets will have stricter limitations because they must fly through any weather above their launch site; this is not possible if there is precipitation, since vertical launch systems typically reach supersonic speeds while still in the weather, resulting in serious damage. The TAV proposed in this paper will be above most weather before going supersonic, and if necessary can maneuver around weather before or during refueling.

Finally, there is the issue of testing. Although the DC-X program has made a breakthrough in the testing of vertical takeoff and landing (VTOL) systems, years of experience with aircraft testing seem to argue that the horizontal takeoff and landing system would involve fewer unknowns and better understood procedures.

Characteristics of Vertical Systems

Vertical launch's greatest advantage is its small footprint. With little requirement for a fixed runway, friendly forces become less predictable to an aggressive, technologically advanced enemy. The best example of this was found in the Gulf War. The United States, with superior intelligence, command and control, and weapons rapidly decimated all of Iraq's fixed air and missile attack infrastructure. Only those systems that were mobile and dispersed survived. The most successful of these systems were the SCUD missiles which continued operations until the end of the war.

A mobile, vertical launch system may retain some of these operational advantages, though not if it is much larger than current mobile missile systems (there is the problem of bridges, tunnels, trafficability, etc.). The question becomes whether enhanced tactical mobility and the resulting increase in survivability is appropriate or necessary in light of the costs associated with the capability.

Hybrid Systems

The weight penalty associated with horizontal takeoff (size of wing, landing gear and support structure) can be reduced through vertical takeoff with horizontal landing--this is essentially what the shuttle does--while retaining some of the reentry and landing advantages. Black Horse, in contrast, achieves the same effect through aerial refueling. The disadvantages of the vertical takeoff horizontal landing (VTOHL) are that the wing, landing gear and associated structure are dead weight throughout all but the final few minutes of flight. This means, first, that the wing has limited utility for a soft launch abort (it's not sized for the vehicle gross weight; part of the reason for the shuttle's expendable bits); second, that the essential problem of vertical takeoff (needing to produce a greater than 1:1 thrust to weight ratio vary rapidly, which drives engine performance) is exacerbated by the extra weight, and finally, that there is little if any margin for error on the first flight (even if airdropped, as shuttle was), which makes the test program more complex and expensive.

Additional Considerations

Other arguments are occasionally raised in favor of vertical launch systems. Most of these are not relevant to the TAV concept discussed in this white paper, but they pose questions that deserve to be discussed.

1) *Few runways in the world have suitable length or weight capacity to handle a horizontal takeoff and landing vehicle in the multimillion pound gross weight class.* Any vehicle, vertical or horizontal takeoff, in this weight class will require specialized launch sites (as a minimum, appropriately stressed concrete surfaces). Huge aerospace vehicles have consistently proved to be costly, unwieldy and generally undesirable unless there is no other way to perform the mission. The TAV concept proposed in this paper is explicitly a product of avoiding gigantism and attempting to minimize the vehicle's takeoff weight.

2) *Horizontal takeoff and landing systems have a more severe sonic boom problem.* This argument is design dependent. If the vehicle is designed to cruise super/hypersonically in the atmosphere (like NASP), it may be a concern. The TAV proposed in this paper is rocket-powered and has no need to fly horizontally. In fact, the flight profile is strictly subsonic until commencement of the orbital/suborbital insertion burn, at which point the TAV basically rotates to a vertical aspect and adopts a trajectory similar to a conventional rocket (perhaps somewhat modified to take advantage of lift early in the flight). The sonic boom/noise problem is, if anything, less than that of a VTOL rocket, since the orbital insertion burn begins at over 40,000 feet vice sea level, and the vehicle goes supersonic at a higher altitude than a VTOL system.

Summary

The question of horizontal takeoff and landing versus vertical takeoff and landing comes down to the interconnected issues of engineering design and operational requirements. The landing gear and lifting surfaces of a horizontal system obviously result in a heavier empty weight, thus less payload. On the other hand, the VTOL system must have significantly more fuel on board to land, and it must take this to orbit in lieu of payload.

The need to operate from a runway imposes some operational limitations. On the other hand, lifting surfaces and the ability to operate like an aircraft offer increases in operational flexibility in other areas, and the number of runways available to a reasonably sized TAV combined with the system's range mean that a threat to all suitable airfields is only realistic in the

most extreme scenarios. In addition, it is not at all clear that a VTOL system requires less infrastructure. A VTOL needs transport for the launch vehicle from its base(s) to a launch area. Fuel transport and storage, payload handling, maintenance, and other logistics functions must all be deployed with the VTOL system to make it work. The horizontal system, on the other hand, makes maximum use of existing infrastructure. On balance, it is our judgment that in the near term and for the missions envisaged by this paper, the horizontal takeoff and landing system is the preferable way to attain the global reach that enables global power.

Attachment C

Manned Versus Unmanned Systems

For years, unmanned aerial vehicles (autonomous or remotely piloted) have been technically possible and lately such vehicles have become more prominent. Cruise missiles, which blur the line between drone and aircraft missions (albeit one-way), have become relatively well accepted. At present, unmanned vehicles do not possess the operational flexibility (in terms of retargeting, alternate missions, etc.) of manned aircraft. On the other hand, manned aircraft are inherently more expensive vehicles, and may be unsuited for certain missions, because of the risk to or the limitations of the crew.

This study considers capabilities for 2020. It is entirely possible that by 2020 techniques such as telepresence, virtual reality displays, and communications links with increased security, reliability, and bandwidth will enable remote piloting of most missions. For a Black Horse type vehicle, remote piloting could include not only launch, payload delivery, reentry and landing (which obviously can be done now by unmanned systems), but also suborbital weapons delivery missions that do not require a human-in-the-loop, and even aerial refueling with a remotely piloted or a drone. The SPACECAST Lift Team agrees that these things are possible and may even be desirable, though there probably will still be missions (even in space) in 2020 where a human presence is advantageous or necessary.

The problem of getting there from here remains, however. In particular, for a Black Horse TAV, there is the issue of performing an aerial refueling operation of an unmanned vehicle, particularly of one with such different performance characteristics as a rocket-powered TAV. There is also a question of how well the performance characteristics of the vehicle can be explored remotely. Chances are that a manned X-program offers the most reliable way of conducting the initial tests. With the adaptability of the human in the cockpit (and a flight test engineer on board as well), well-established test and development procedures can be used. Starting with an unmanned vehicle would require development of at least some new test procedures in addition to the vehicle test program. These kinds of development plans would inevitably incur large delays in concept validation.

Another issue is the assertion that designing the vehicle for on-board human operators will impose unacceptable costs and performance penalties. This is not necessarily so. First, unlike

conventional rocket designs that derive from missiles and are inherently adaptations of throw-away, one-way designs, reusable aerospace vehicles must "take care" of themselves. In other words, the vehicle must survive its flight, and the ways it does this are relatively easy to adapt to human requirements. For example, TAV space launch vehicles are unlikely to execute 50G turns or reenter like ballistic missile warheads. The former is unnecessary, and the latter imposes severe constraints on reusability. The primary issue for humans are reliability, nondestructive abort, recovery and landing, life support, and instrumentation. All of these except the last are inherent characteristics of Black Horse vehicles.

The issue of life support and instrumentation is mainly one of cost versus benefit. For a Question Mark 2 X-program, an austere cockpit (like the U-2) is certainly acceptable. With limited duration operations, oxygen, other consumables, and general crew equipment will be minimal. Instrumentation requirements are approximately the same between manned and unmanned X-systems, though the requirement for displays and controls in a manned system means some extra weight. The overall weight penalty (about 2000 pounds, according to the Black Horse initial concept study) associated with having two crew members aboard is significant, since much of that weight could otherwise be payload, but the goals of the program must be kept in mind. Given the unique nature and type of unknowns about this system, the X-vehicle should not be driven by maximizing payload.

On balance, operational TAVs may be unmanned, but this is an issue for cost and operational effectiveness analyses. We believe a manned X-program is the right way to start and is a prerequisite to exploring future unmanned options.

Attachment D

Weapons Delivery Vehicle Type Tradeoffs

Weapons Delivery Vehicle Versus Satellite-Based Weapons

The energy advantage inherent with space basing is equal for both weapons delivery vehicles and satellite-based weapons and is an advantage of both. The operational utility and survivability of the weapons delivery vehicle is superior to satellites as described below. Satellites have positioning problems and require constellations for guaranteed response times of less than one hour. Even a constellation of satellites requires sequential operations, and a significant delay incurs as each satellite orbits into position. The weapons delivery vehicle will have the ability to attack in mass and with similar first response times as a constellation.

Satellites are both observable and fixed in their orbits. This makes them predictable and vulnerable to the enemy's counterspace weapons. Any sort of disposable countermeasures and some active defense systems would result in hazardous space debris. A first strike directed against our weapons satellites could deny us their capability. The TAV weapons delivery vehicle operates in far less predictable suborbital flight paths which can take advantage of enemy vulnerabilities. The vehicle can use active countermeasures in a suborbital trajectory since any debris will fall back to earth.

Satellites are a fixed, obsolescing asset once in orbit. The onboard weapons failure rates increase over time and their capability will eventually limit the effectiveness of the system. Once a satellite is in orbit, its payload type is fixed allowing little operational flexibility, and once it expends its munitions it is useless until reloaded. These problems are not applicable to the modular weapons used with a TAV since they are stored on the ground and are available for maintenance and upgrade. The modular concept allows configuring the payload to match the target prior to each mission as well as rapid reloads following missions.

Weapons satellites also suffer from a legal and a political disadvantage. International agreements prohibit basing of nuclear weapons in space. Although SPACECAST does not propose using nuclear weapons, the basing of *any* weapons in space will inevitably raise a verification issue and may be viewed internationally as provocative. Politically, countries may resist space basing of weapons of any kind, whereas countries may accept delivery of weapons

through space, especially by a TAV which is subject to positive control and recall throughout much of its flight. A satellite's main advantage is presence in those cases when a weapons delivery vehicle is unable or undesirable for use.

Weapons Delivery Vehicle Versus Intercontinental Ballistic Missiles (ICBM)

The prime advantage of converting surplus ICBMs is sunk costs. They are available and it seems like a waste to ignore the capability they might offer. The TAV and ICBMs have similar delivery capabilities for kinetic energy type projectiles. However, the ICBM has no capability to bring weapons back and would therefore be a poor choice for directed energy weapons in a counterspace role. In general, missiles offer less operational flexibility--basing, relocatability, deployability, targeting, flight paths, alternative missions, and payloads--than a TAV. In the potentially high-tempo world of the future, political and military environments could change rapidly. Once launched, ICBMs cannot be recalled, whereas TAVs can be recalled until weapons release, or can even go to orbit and wait for weapons release authority. Moreover, cooperative missile launch notification protocol may, in the future, make surprise less likely. TAVs are not included in such protocols.

Conversion of old ICBMs also raises practical problems such as the remaining life of the missiles and the permissibility of such a conversion under the Strategic Arms Reduction Talks (START) treaties. However, if these problems were overcome, a combination of ICBMs and the weapons delivery vehicle may offer an attractive long-term option to combine the cost-effectiveness of using paid for systems with the flexibility and sustainability of the weapons delivery vehicle.

Weapons Delivery Vehicle Versus Intercontinental Artillery

Intercontinental artillery relies on a fixed installation due to its size and is therefore vulnerable to a capable adversary. This vulnerability is minimized for the weapons delivery vehicle as explained in the defensive tactics section. Intercontinental artillery would also be limited in the number of trajectories available, unless the tubes/rails could be slewed to different azimuths.

Weapons Delivery Vehicle Versus Conventional Aviation

The purpose of the weapons delivery vehicle is not to replace the projected fleet of combat aircraft. It could become part of a future composite aerospace wing as described at the beginning of the paper. The TAVs advantages of speed, security, and lower vulnerability make it a valuable complement to existing conventional combat forces. Targets requiring large amounts of high explosive, loiter time, or visual identification will still be suited to conventional aviation.

Attachment E

Weapons Types for Suborbital or Transatmospheric Vehicles

Kinetic Energy Weapons

This class of weapons capitalizes on the destructive effects of a relatively small, hypersonic projectile impacting a target's surfaces.[50] These penetrators work best against hard surface targets that resist the projectile. This allows them to impart sufficient energy to the target to generate destructive weapons effects. Kinetic energy penetrators will require a wide range of sensor options for reliable target identification and guidance to precise aimpoints against fixed and moving targets under all conditions. Finally, penetrators should be developed in a variety of sizes to tailor weapons effects to a target and allow carriage of the greatest number of weapons per module.

High Explosive Weapons

High explosive options may still be necessary. High speed projectiles may require additional P_k because of accuracy or damage mechanism limitations (they might pass right through thin-skinned targets without causing sufficient damage). In these cases conventional high explosives can make up for the lost weapons effects. Additional devices for slowing projectiles might be necessary to allow independent search and targeting, mining, or for specific weapons effects. The SPACECAST team envisions a maneuverable reentry vehicle that both delivers the payload to the target area and controls the velocity prior to releasing appropriate high explosive submunitions.

Directed-Energy Weapons

Directed-energy weapons offer significant benefits but also have numerous disadvantages. The disadvantages center around high infrastructure requirements (power generation, pointing mechanisms) and propagation of sufficient energy through the atmosphere to target surfaces.

Infrastructure means weight. This problem reduces the weapons on a vehicle to a low number. The end result is fewer targets hit on a single pass. This limitation combined with energy loss to the atmosphere results in less than optimum performance against ground targets.

Until these limitations are corrected, directed-energy modules should be used for the counterspace mission. This mission offers no energy loss to the atmosphere, disables targets with minimum space debris, and may allow multiple targeting of space platforms per mission.

Attachment F

Characteristics of a Black Horse JP-5/H_2O_2 Fueled Transatmospheric Vehicles

Development

Available technology
- engines
- structure
- thermal protection
- avionics

X-vehicle program
Incremental flight test
Verify procedures
Verify operations cost assumptions
Proof of concept
Ability to crash build

Logistics

JP-5/8/10
Commercial H_2O_2
- 70% to 98%
- purified on site
- mobile equipment
- resell byproduct
- easily storable

Engines
- simple (relatively)
- spares required
- parts required

KC-135Q/T
- number needed?

Maintenance

R&M design
Engines
- reliability
- lifetime

Avionics
Landing gear
Thermal surfaces
Control surfaces
Composite materials
Landing gear, doors

Launch

Gross take-off weight
Payload handling
Fueling procedures
Preflight checks
Taxing
Takeoff roll
Abort procedures

Refuel

Take on 140,000 lb H_2O_2
Rendezvous time
- time to altitude
- fuel to altitude
- monopropellant operations?

Boom time
- refuel rate

Refueling procedures
- airspeed
- latch controls to tanker
  - via boom connection

Visual check by tanker
Ability to tank JP also?

Orbit Insert

Aircraft navigation system
GPS receiver
Integrated flight control computer
Insertion setup
- latitude, longitude
- azimuth
- ATC clearance

Precise insertion
- computer throttling

Available inclinations
- virtually any

On orbit

Ground control
- Air Traffic Control to Space Traffic Control hand-off

Communications links
On-orbit fuel
- mission dependent

Payload deployment
Other missions
- rendezvous
- assembly
- capture/repair
- fueling

Endurance
- crew systems

Deorbit

Communications
Criteria
- landing site

Procedures
Flight path
Reentry loads
- thermal
- structural

Cross-range capability

Recovery/Turn

Landing
- dead stick?
- go-around capability?

Weather limits?

Suborbital Operations

Missions
- weapons delivery
- space control

Range
Fuel reserve
- 2 suborbital flights
- loiter time

Payload?
Tank at destination?
- Operations Security

Attachment G

X-Program Details: Black Horse and the Question Mark 2

The goal of the X-program is to incrementally and affordably prove the concept, procedures and technologies associated with a noncryogenically fueled transatmospheric vehicle capable of air-to-air propellant transfer. This paper refers to this class of vehicles as Black Horse vehicles, the first of which would be called the Question Mark 2 to recognize it as a continuation of innovative air-to-air refueling demonstrations.

Analysis and Design Issues

The claims made for the Black Horse vehicle are based on preliminary design work done for the USAF Phillips Laboratory under the direction of Capt Mitchell Clapp, a flight test engineer, former TPS instructor, and the only Air Force "crewmember" qualified on the DC-X, who developed the initial concept. Aerodynamic and structural calculations were performed by Dan Raymer (Conceptual Research Corporation), the designer of the X-31, former Chief of Advanced Design at Lockheed and author of *Aircraft Design -- A Conceptual Approach*, using the RDS-Professional computer-aided design and analysis system, with weights estimated statistically using the Vought fighter equations. Aerothermodynamics estimates including reentry were done by Ed Nielsen, a former NASP engineer, of WJ Schafer and Associates. Rocket design was performed by engineers at WJ Schafer with over 80 years of design experience at Rocketdyne and elsewhere. Flight trajectory and parametric performance studies were done using NASA's POST (Program to Optimize Simulated Trajectories) software. The design has been iterated on a system level, and has been shown to be internally consistent. Key assumptions were: reentry using NASA HL-20 profiles (generated from the MINIVER and LAURA codes), which should have higher heat loads and transfer rates than Black Horse due to the latter's lower wing loading and deceleration high in the atmosphere; an all-aluminum structure; thermal protection and external materials using 1980 technology; and the size of the vehicle constrained by the maximum propellant offload . In short, while the design is preliminary, it was not done carelessly or by amateurs. The SPACECAST Technology Team, including AFIT, has reviewed the calculations and found no obvious errors, unsupportable assumptions, or improper methods.

The top priority before embarking on an X-program would be a rapid but thorough completion of the analysis and design effort. This would concentrate on four areas: a detailed

reentry analysis to provide complete data for designing the thermal protection system, trajectory modeling to further refine the performance requirements for this particular design, a detailed structural analysis to include an evaluation of the possible application of composite structural elements, and rigorous engineering cost estimates to substantiate the assertion that an X-program could be done for close to $100M.

Basic Program

The basic X-vehicle program includes the building of two Black Horse TAV airframes, an appropriate number of noncryogenic rocket engines, and the conversion of at least one KC-135Q tanker aircraft to carry hydrogen peroxide. Testing would proceed along the lines of classical aircraft flight testing.

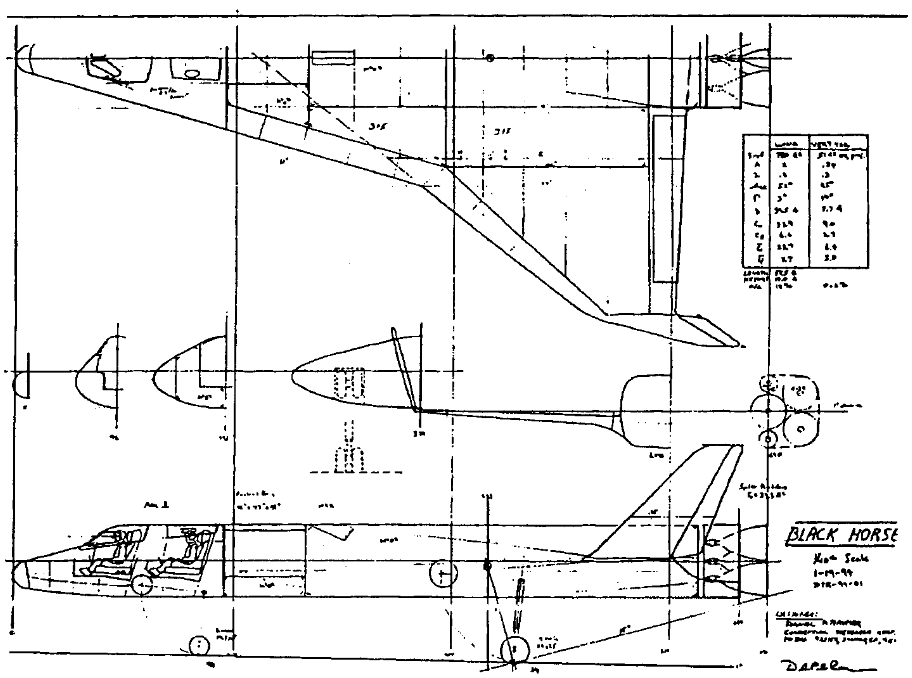
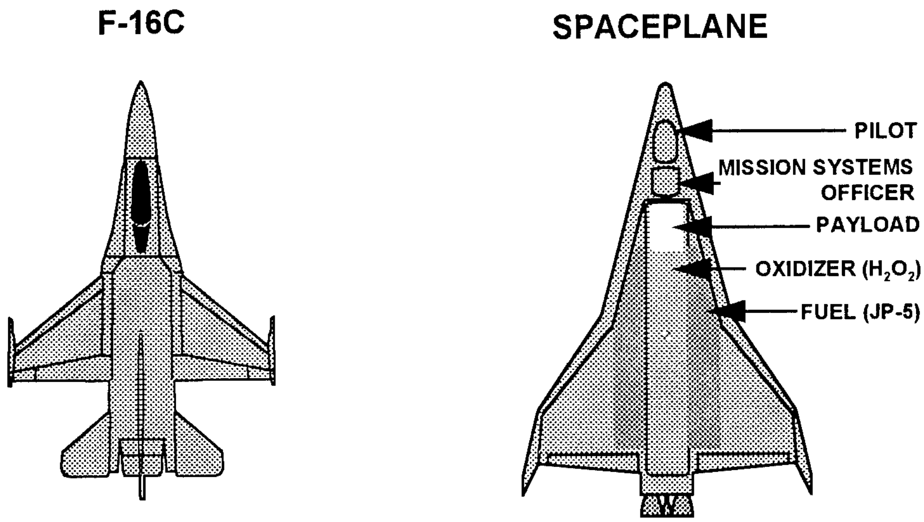


Figure 3: Black Horse X-Vehicle ("Question Mark 2") Engineering Sketch

<u>The Vehicle</u>. The initial design concept for the X-vehicle (shown in figure 3) was sized around the maximum amount of propellant (in this case 147,000 pounds of hydrogen peroxide, the oxidizer) that can be carried by a single KC-135Q. (Because the oxidizer is heavier than jet fuel and is burned at a 7:1 mixture ratio, this is the logical propellant to transfer.) This results in a vehicle that is 57.5 feet long with a 39.5 foot wingspan. The wing is a double-delta platform with a large strake blended into the fuselage and using two wingtip vertical stabilizers. As initially

designed, the vehicle is approximately 8 percent aerodynamically unstable at subsonic speeds (about the same as an F-16), neutrally stable trans-sonically, and about 10 percent stable at hypersonic speeds. Gross takeoff weight is approximately 50,000 pounds (see Table 2 below). Propulsion is provided by seven rocket engines, two primarily for ascent and five main engines, the difference being the exhaust nozzles (the ascent engine nozzles are optimized for low altitude performance). Figure 4 shows a planform comparison to an F-16. Table 2 shows some basic vehicle characteristics.



	F-16C	Spaceplane	
Empty Weight	18,238	14,958	pounds
Max T/O Weight	42,300	48,452	pounds
Span	32.8	39.5	feet
Length	49.5	57.5	feet
Height	16.8	17.0	feet
Wing Loading (peak)	1200	550	lb/ft^2
Payload	12000	1000	pounds

Figure 4. Planform Comparison of F-16 and a Black Horse Vehicle[51]

Table 2
Estimated X-Vehicle Characteristics[52]

Empty Weight	14,958 lb
Gross Takeoff Weight	48,452 lb
Payload	1,000 lb
Takeoff Distance	2,500 ft
Tanker	KC-135Q
Propellants	JP-5/Hydrogen peroxide
Gross Lightoff Weight	187,000 lb
Crew	2
Ferry Range (unrefueled)	3,200 nm
Suborbital Radius	5,000 nm

Test Program. Testing would progress from engine static firings through high speed taxi tests to takeoffs, landings (powered and unpowered), and basic aerodynamic handling characteristics. When the envelope had been sufficiently expanded, formation flying with the tanker, initial hookup and finally propellant transfer testing could begin. In parallel with this, the other TAV could be conducting high-speed, high-altitude flights, to include ballistic trajectories, using the maximum amount of propellant that can be loaded on the ground. This will naturally be followed by increasing altitude suborbital trajectories following aerial propellant transfer; these tests will demonstrate not only boost phase but reentry performance. The test program will culminate in orbital flights, eventually demonstrating payload delivery. The thrust profile of an orbital mission is shown in figure 5.

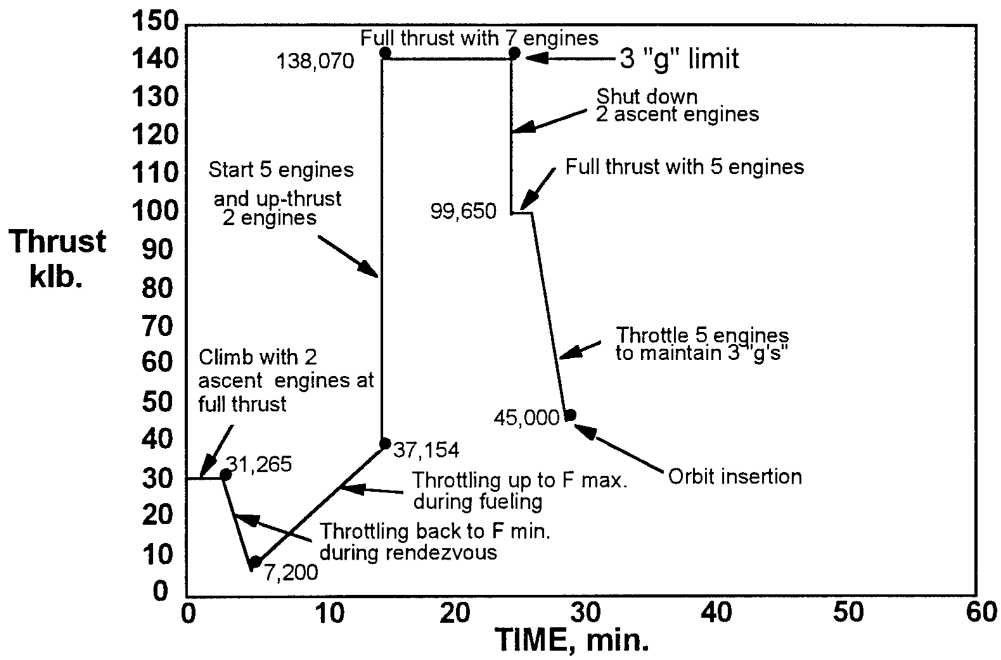


Figure 5. Black Horse Type Vehicle Thrust Profile[53]

Excursions

Several variations of the above program are possible, ranging from a quick-start effort maximizing use of off-the-shelf components to an elaborate series of experiments building on a basic effort.

Quick Start. Two of the long-lead items for the X-program are the airframe and the engines. Key questions include the aerodynamic properties of the vehicle, refueling procedures, and reentry characteristics. A large portion of the test program could be conducted with a nonorbit-capable vehicle, especially if that vehicle could be upgraded later to achieve orbit.

There is some evidence to suggest that such a program could be put together without first creating a paper mountain of design studies. Burt Rutan (of *Voyager* fame) has taken the initiative to design a composite airframe for a Black Horse vehicle.[54] This or a similarly entrepreneurial design could form the basis for a prototype TAV.

Initially, the vehicle could use spare AR-2 engines (used on the NF-104-D, nine are government-owned and currently in storage at Rocketdyne). Production of additional AR-2 engines would be relatively inexpensive. Seven of these engines, operating at full thrust, would be adequate to carry out full refueling tests, all atmospheric flight and a large portion of the

suborbital flight test program. Since the number of engines is the same as in the basic Black Horse design, no major airframe changes would be needed to pull the AR-2s and replace them with more capable engines when the latter become available. The new engines would permit further expansion of the flight envelope to include orbital operations.[55]

Avionics, landing gear, crew equipment, and so forth could be borrowed from other programs or taken from stock (as was done on the X-29 and X-31) and replaced with more capable subsystems as needed or desired.

Fuel Enhancements. Historical experience with kerosene-fueled rockets and preliminary theoretical analysis suggest that the engines of a Black Horse vehicle, if properly designed, should be able to burn almost any kind of hydrocarbon fuel. Initial experimentation could focus on the specific-impulse-boosting properties of additives such as quadricyclene. Later experiments could examine the effects of using higher-density fuel such as JP-10, and even lower-quality fuel (e.g. for austere-field operations). Long-term experiments could explore the use of metastable or other exotic fuels as these become available.

Improved Structures. If the initial airframe is not a composite structure, a later Black Horse X-vehicle will want to test such a structure (every pound of reduced structural weight is an additional pound for available payload). In fact, such a structure is not only desirable from a weight standpoint, but from a thermal one: composites can handle greater thermal loads than aluminum, thus simplifying the thermal protection problem. As mentioned above, even a full composite airframe may be a near-term capability.

Alternative Engines. Aside from upgrading with higher-performance conventional rocket engines, a Black Horse TAV offers an attractive test bed for other propulsion concepts. One example of this is a Martin Marietta ducted rocket, which could be mounted on the rear of the airframe between the vertical tails.[56] The reason for considering an engine like this is twofold: first, although any airbreathing system has diminishing returns at high speeds, a ducted rocket could provide both a performance boost at lower altitudes and economize on the use of oxidizer. Second, because of the ducting effect, such a rocket would be less noisy (much as a turbofan is less noisy than a turbojet), a significant potential benefit for both future commercial operations and expanded use of military airfields in peacetime.

Lob/Toss Launch. One way to increase the amount of payload is to use the TAV as a first stage, and lob an upper stage at the peak of a suborbital trajectory. Experimentation with this kind of release and launch could be added to an X-program at any time.

Weapons Delivery. Weapons delivery could be similar to the lob/toss launch of a satellite, but with the intention of the payload reentering the atmosphere. Most of the weapons described earlier in this paper could be developed and tested using the X-vehicle.

Larger tanker/higher fuel transfer rate/dual propellant transfer. Since the initial Black Horse design was sized around the maximum single-ship KC-135 offload, a larger available propellant offload would allow a larger, more capable Black Horse type vehicle. Higher fuel transfer rates through improved pumps and/or larger transfer tubes would mean less time on the boom and ease any aerial refueling problems. Dual propellant transfer (not impossible, since hydrogen peroxide and JP do not spontaneously combust, but not a trivial problem either) would allow extended operations aloft, repeated access to orbit, or returns from long-range suborbital missions without landing.

Transatmospheric Vehicle-to-Transatmospheric Vehicle Refueling. This is another method to increase payload capacity or to provide the fuel needed to take a given payload beyond LEO (even to the moon). "Buddy tanking" of TAVs offers the prospect of very high altitude and high speed refueling. The required testing could be accomplished after initial program goals have been met.

Carrier Vehicles. Some scenarios may favor launching the TAV from a carrier vehicle; indeed this is the more traditional design. Use of a proven "orbiter" (the Black Horse) could simplify the overall system development program if a decision is made to develop the carrier vehicle.

Unmanned Operations. Once the performance characteristics of the TAV are well known and tested throughout the flight envelope, a program could test an unmanned flight control system to include the aerial refueling of the vehicle. This would directly support the development of uncrewed operational variants of the TAV for missions not requiring man in the cockpit.

Attachment H

Black Horse Operating Cost Estimates

Although SPACECAST is not necessarily constrained by cost issues, the fact that a major problem with spacelift systems is their cost, and the fact that reusable vehicles have often claimed extremely good recurring cost-per-pound to orbit numbers, demand that this paper at least explain the basis for the estimate of Black Horse operating costs. Note that this illustration makes no attempt to estimate system acquisition or total life cycle costs at this point; it is solely intended to show a credible basis for the operating cost estimates. The cost model is derived from the actual operating cost data of the SR-71.[57] The basic assumptions are as follows:

- 385 personnel (crew, maintainers, administrators, etc.)
- basic payload handling, similar to SR-71 mission system processing, is included
- 8 TAVs and 8 supporting tankers
- Each vehicle flies once per week; 400 total sorties per year
- Base/site operations and maintenance are $10M per year
- Additional site maintenance per flight is $25,000
- Overhead cost per person is $130,000 per year
- Propellant cost is $0.20/lb for JP-5, $0.68/lb for H_2O_2
- 21,000 pounds of fuel are used per sortie (not including tanker)
- 155,000 pounds of oxidizer are used per flight

The table below shows the cost-per-pound to orbit using the above assumptions and varying first the amount of payload carried, then using the baseline payload but a smaller manning requirement.

	Baseline	Large Payload	Medium Payload	Small Crew	Few Flights (100/yr)
Number of people	385	385	385	200	200
Ops cost multiplier	2.37	2.37	2.37	1.82	4.28
Payload per flight (lb)	1,000	5,000	3,000	1,000	1,000
Total lift per year (lb)	400,000	2,000,000	1,200,000	400,000	100,000
Personnel cost per year	$50,050,000	$50,050,000	$50,050,000	$26,000,000	$26,000,000
Propellant cost per year	$43,840,000	$43,840,000	$43,840,000	$43,840,000	$10,960,000
Total ops cost (incl base)	$103,890,000	$103,890,000	$103,890,000	$79,840,000	$49,960,000
Propellant cost per flight	$109,600	$109,600	$109,600	$109,600	$109,600
Personnel cost per flight	$125,125	$125,125	$125,125	$65,000	$260,000
Total cost per flight	$259,725	$259,725	$259,725	$199,600	$469,600
Cost-per-pound in orbit	$259.73	$51.95	$86.58	$199.60	$469.60

The scenarios above do not explore the entire range of possibilities, but several observations are possible even from this limited sample. First, this system is not cheap to operate relative to aircraft; in fact the numbers are comparable to SR-71 operating costs (often quoted as about $100,000 per flight hour). The cost-per-pound to orbit, however, even under fairly pessimistic assumptions (smallest payload, relatively few flights, high nonflying operations cost), is still quite low. Perhaps this shows just how expensive our current space operations really are (at $10,000 per pound to orbit and up), and how large the potential for improving that figure is with reusable launch vehicles.

The table also highlights the fact that, even with a modest increase in payload capability from the X-vehicle to an operational system, cost-per-pound to orbit can shrink dramatically and the number of tons placed on orbit in a year gets quite large. A redesign of satellites (smaller and/or modular systems, design for shorter lifetimes) and a new concept of space operations to take advantage of this new means of space access (tailored missions, surge, and responsiveness) would offer both further cost savings and tremendous improvements in the operational utility of space.

Notes

[1] The name Black Horse has multiple origins. It is first a tribute to the British Black Arrow and Black Knight programs, which demonstrated the basic propellant concept many years ago. The name also is a link to the SR-71 Blackbird, which provides the tanker aircraft and the basis for the operations cost model. These connections are explained in more detail later in the paper. The Horse part of the name honors an animal that has carried cargo and people in peace and in war. Finally, Black Horse sounds a lot like dark horse, which this system certainly is in the launch systems race.
[2] In honor of the first aircraft to demonstrate aerial refueling. Thanks to Dr F.X. Kane for reminding of us the lineage of experimental programs and for suggesting this name.
[3] Drawing from a conceptual study done by WJ Schafer and Associates and Conceptual Research Corporation for Phillips Laboratory, January 1994.
[4] For example, much monolithic satellite design (sizing, folding/deployable elements and so forth) is based on making maximum use of a single launch vehicle envelope. In contrast, under this approach, a pre-wired structure, solar panels, subsystem modules and payload modules could be designed with relatively simple, quick connect interfaces (work on the space station assembly process would probably be used here) for manual or automated assembly. Active structural control would ensure that necessary alignment tolerances were met after assembly.
[5] See, for example, Air Force Mission Need Statement 202-92, Military Aerospace Vehicles.
[6] US Air Force Space and Missile Systems Center (SMC/XR) "Visions" study, for example. Almost all space panels conclude that spacelift is the critical element in developing space applications.
[7] Essentially, all of the White Papers in SPACECAST have assumed more routine, or at least affordable, access to space as a prerequisite for their implementation.
[8] The Hon Sheila E. Widnall, Secretary of the Air Force, speech to the National Security Industrial Association, 22 March 1994.
[9] Ibid. This situation is often referred to as "the tyranny of the payload."
[10] Prepared statement of Gen Charles A. Horner, CINC United States Space Command to the Senate Armed Services Committee, 22 Apr 93
[11] DoD Space Launch Modernization Plan, April 1994.

[12] Ibid. See also the SPACECAST 2020 White Paper on Space Operations and Space Traffic Control
[13] See the Vice President's Space Advisory Board, "The Future of the US Space Launch Capability: A Task Group Report", November 1992 (the Aldridge report) for cost goals for Spacelifter. Other sources (cited in Air Force Institute of Technology alternative lift briefing) generally give higher costs-per-pound to orbit for the small expendable lift systems that for large expendables.
[14] Aldridge report, NASP studies, Delta Clipper studies.
[15] E.C. Aldridge interview with author during first Advisory Group visit, January 1994.
[16] For example, DARPA's Advanced Space Technology Office has produced several articles on the capabilities, operational benefits, and potential cost savings of small, modular satellites.
[17] Horner testimony (see note 8), Widnall speech (note 6)
[18] Operations costs for Kennedy Space Center and Vandenberg run into billions of dollars per year, and it takes weeks to months to refurbish a launch pad following a launch for the next event.
[19] Clapp and Hunter, A Single Stage to Orbit Rocket with Non-Cryogenic Propellants
[20] McDonnell Douglas Diagram in Bill Sweetman, *Aurora: The Pentagon's Secret Spy Plane,* (Osceola, WI: Motorbooks International Publishers and Wholesalers, 1993).
[21] Ibid.
[22] "Advantages of Hydrogen Peroxide as a Rocket Oxidant," by David Andrews, Journal of the British Interplanetary Society, July 1990. See also, Project RAND, "Propellants for Supersonic Vehicles: Hydrogen Peroxide", RA-15046, Douglas Aircraft Company, August 12, 1947.
[23] Capt M. Clapp, DC-X flight crew member, interview with author January 1994.
[24] Although more detailed study is needed, the relatively low take off weight of the TAV described in this paper should result in a noise level similar to that of an F-15 in afterburner. Noise is related to exhaust jet speed and surface area, and while the TAV exhaust is about twice as fast, the area should be less.
[25] Of course, this technique is not limited to horizontal takeoff and landing vehicles; it was even considered for the Apollo mission, according to Dr F. X. Kane. However, a winged horizontal takeoff and landing vehicle offers the best performance match to existing (and hence the least expensive option) tanker assets.
[26] For NASP, structural design and materials problems due to sustained hypersonic airbreathing flight, fuel tankage, and engines. For carrier/orbiter concepts, a large, expensive, unique carrier vehicle with considerable development costs of its own.
[27] The environment a TAV must operate in is no more hostile to human life than the environment a U-2 or TR-1 routinely operates in.
[28] Conversation with Capt M. Clapp, USAF Phillips Lab, May 1994. The number comes from the rule of thumb that landing gear will weigh approximately 3 percent of gross takeoff (or landing, whichever is greater) weight.
[29] Ibid.
[30] Full details are contained in the paper and briefing from WJ Schafer and Associates and Conceptual Research Corporation, January 1994
[31] Ibid.
[32] Briefing from USAF Phillips Lab (Capt Clapp) to SPACECAST, 29 Apr 1994. Performance numbers and flight profiles were validated using NASA's "Program to Optimize Simulated Trajectories" (POST).
[33] Project Forecast II, (June 1986); Mission Applications Document, (22 July 1990); and Force Applications Study, (13 June 1991)
[34] T.O. 1-1M-34, SUU-64/B, Tactical Munitions Dispenser, 31 May 1991, 1-110.
[35] DAS-TR-89-1, *Comprehensive On-Orbit Maintenance Assessment (COMA) (*Kirtland Air Force Base, NM; Directorate of Aerospace Studies, 31 March 1989), 61.
[36] Op. Cit, note 23
[37] From a Rocketdyne briefing on the NF-104D program, undated, on file at Phillips Laboratory.
[38] Paper and briefing from WJ Schafer and Associates and Conceptual Research Corporation, January 1994.
[39] The design assumes a 98% efficient injector, for example. current engine designs (the space shuttle main engine, for example) achieve 99.8% efficiency.
[40] A ducted rocket uses the combustion and exhaust mechanisms of a conventional rocket, but gets its oxidizer (atmospheric oxygen) by using air intakes instead of an on-board supply. This has particular advantages at lower altitudes and speeds. Martin Marietta, among others, has design concepts for this type of system.

[41] Based on Phillips Laboratory parametric studies.
[42] AFSC/DAS study.
[43] According to figures in the KC-135Q "Dash-1," the tanker will be volume (not weight or center of gravity) constrained in the amount of hydrogen peroxide it can carry. This results in a maximum load of about 147,000 pounds. The entire amount can be transferred in approximately 11 minutes. The KC-135Q offload rate is 1200 gallons per minute, and since hydrogen peroxide (at 11.92 pounds per gallon) is substantially denser than jet fuel, this results in a propellant weight transfer of about 14,300 pounds per minute.
[44] Clapp and Hunter. Page .
[45] Paper and briefing from WJ Schafer and Associates and Conceptual Research Corporation, January 1994.
[46] Memo from Phillips Lab XPI, dated 20 March 1994
[47] See, for example, the briefing "Economic Considerations of Hypersonic Vehicles and Space Planes," by G. Harry Stine and Paul C. Hans, The Enterprise Institute, 1990.
[48] Aerial refueling is now as common in military air operations as a beverage service is on commercial flights, and it is usually (and rightly) thought of as a way to extend the range and endurance of aircraft. What hasn't been fully appreciated was that this has also affected the design of aircraft, i.e. a fighter can have global range--if it can refuel often enough--without carrying all that fuel at takeoff. What's new is applying this concept to a space-faring vehicle. For the concept to become commercially viable, commercial operators will also have to embrace air refueling as a routine operation, though this should be no greater leap than the first commercial aircraft or the first commercial jets.
[49] Boyd lecture to SPACECAST, October 1993.
[50] Force Applications Study, 13 June 1991.
[51] Figure from Phillips Laboratory briefing on the Black Horse concept.
[52] Op. cit., note 32.
[53] Figure from op. cit., note 33.
[54] Capt M. Clapp Interview with author , USAF Phillips Lab, 5 April 1994.
[55] Ibid.
[56] Ibid.
[57] Max Hunter, "Experimental Space Craft," *Journal of Practical Applications in Space*, Fall 1993.

UNCONVENTIONAL SPACELIFT

Introduction

In late February 1994, Lt Gen Jay W. Kelley, Air University (AU) Commander and Chairman of the SPACECAST 2020 study, asked the faculty of the Graduate School of Engineering at the Air Force Institute of Technology (AFIT) to investigate unconventional approaches to solving our national spacelift problems (attachment). This AFIT study, designed to complement the conventional spacelift study conducted by one of the SPACECAST 2020 teams at AU, was chartered to find ways to launch payloads from the Earth's surface to low-earth orbit without the use of conventional chemical combustion (fuel and oxidizer).

Selected faculty from the Departments of Aeronautics and Astronautics, Electrical and Computer Engineering, Engineering Physics, and Operational Sciences and the SPACECAST 2020 Technology Team worked together to collect and evaluate over two hundred separate references, consisting of more than 3,500 pages of text and covering almost one hundred different unconventional launch techniques. The vast majority of these reference materials were input to a content-retrieval-based document imaging system, provided by Excalibur Technologies Corporation, greatly facilitating the effort. Techniques were evaluated for engineering and scientific feasibility. Those techniques deemed to violate physical principles were quickly discarded from further consideration.

Technical Considerations

Several factors determine the feasibility of any technical solution. The first factor is Newton's Third Law: For every action there is an equal and opposite reaction. To achieve orbital velocity, sufficient momentum must be provided to the payload and the launch vehicle. To do this, typical propulsion systems must either expel a lot of mass at low velocity or a small amount of mass at high velocity. That is, the thrust (rate of change in momentum) needed, F, equals the product of the mass flow rate, dm/dt, and the exit velocity of the fuel, v_e, or

$$F = \frac{dm}{dt} v_e.$$

The thrust, accumulated over time, provides the needed momentum.

A primary figure of merit for any propulsion system is the specific impulse, I_{sp}, which is measured as the impulse (change in momentum) provided per unit weight of fuel expended. The specific impulse, for conventional combustion systems, is proportional to the square root of the combustion chamber temperature over the molecular weight of the fuel. That is,

$$I_{sp} \propto \sqrt{\frac{T_c}{MW}}$$

where T_C is the combustion chamber temperature and MW is the molecular weight of the fuel. The propulsion system is most efficient (has the highest specific impulse) when the chamber temperature is high and the molecular weight of the fuel is low. In any real system, the chamber temperature will be limited by the material properties of the combustion chamber. For high-thrust systems, hydrogen is the best fuel since it has the lowest molecular weight.

Methodology

Of the one hundred different launch techniques examined, most were eliminated because they failed to pass one of the following two tests:

- Although their specific impulse was great, their thrust-to-weight ratio was not sufficient to launch from the Earth's surface to low-earth orbit. To permit Earth-to-orbit access, a propulsion system must provide greater than a 1:1 thrust-to-weight ratio. While many of these systems hold promise for an on-orbit transfer vehicle, they do not solve the basic problem of launching to low-earth orbit. Figure 1 shows that of the potential technologies available, only chemical propellants and nuclear fission[1] provide sufficient thrust to merit further consideration.

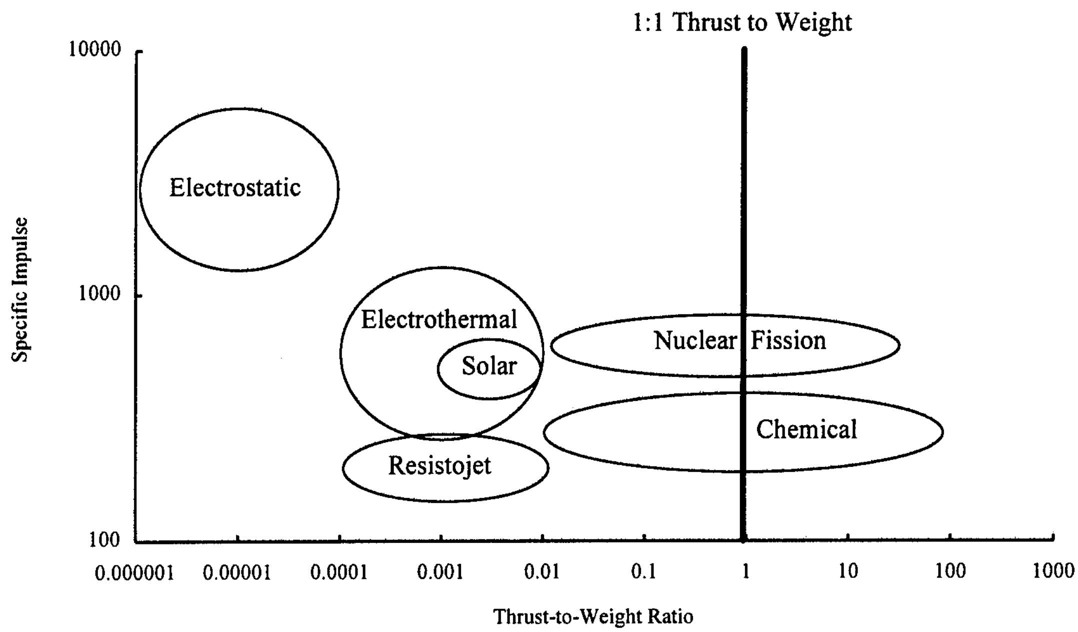


Figure 1. Specific Impulse versus Thrust-to-Weight Ratio[2]

- While theoretically possible, some approaches were not operationally feasible. These included systems such as laser propulsion requiring huge external power sources (on the order of a billion watts) and would have extreme difficulty with atmospheric propagation of the required directed energy.

These constraints narrowed the list of concepts to high-energy-density fuels, antimatter, nuclear, and tethers. These concepts are discussed below.

High-Energy-Density Fuels[3]

The High-Energy-Density Materials (HEDM) Program is a research and development effort managed jointly by the Air Force Phillips Laboratory and the Air Force Office of Scientific Research. The HEDM program represents a collection of concepts to increase energy content in chemical bonds of non-nuclear materials. The fundamental premise for all chemical propulsion is that weakly bound atomic structures rearrange into very strongly bound atomic structures with the release of energy. Strongly bound chemical materials are very well known. Therefore, HEDM investigators are searching for high-energy metastable materials which release much more energy than liquid hydrogen/liquid oxygen combustion, yet are sufficiently stable to be practical propellants. One generally expects high energy release to correlate with instability. The

HEDM program explores for candidate materials which are exceptions to this trend. Practical HEDM propulsion systems will require that the chemical reaction products serve as propulsion exhaust. So, to achieve high specific impulse, atoms in candidate metastable structures must be light atoms which produce light product molecules, preferably diatomic molecules. Since the chemical reaction products are exhausted, they must be environmentally benign.

It is important to point out here that improvements in payload to orbit do not track linearly with improvements in specific impulse. For example, at an I_{sp} of 450 seconds, a ten-percent improvement in specific impulse would produce a twenty-percent improvement in payload to orbit. This relationship is illustrated in figure 2.

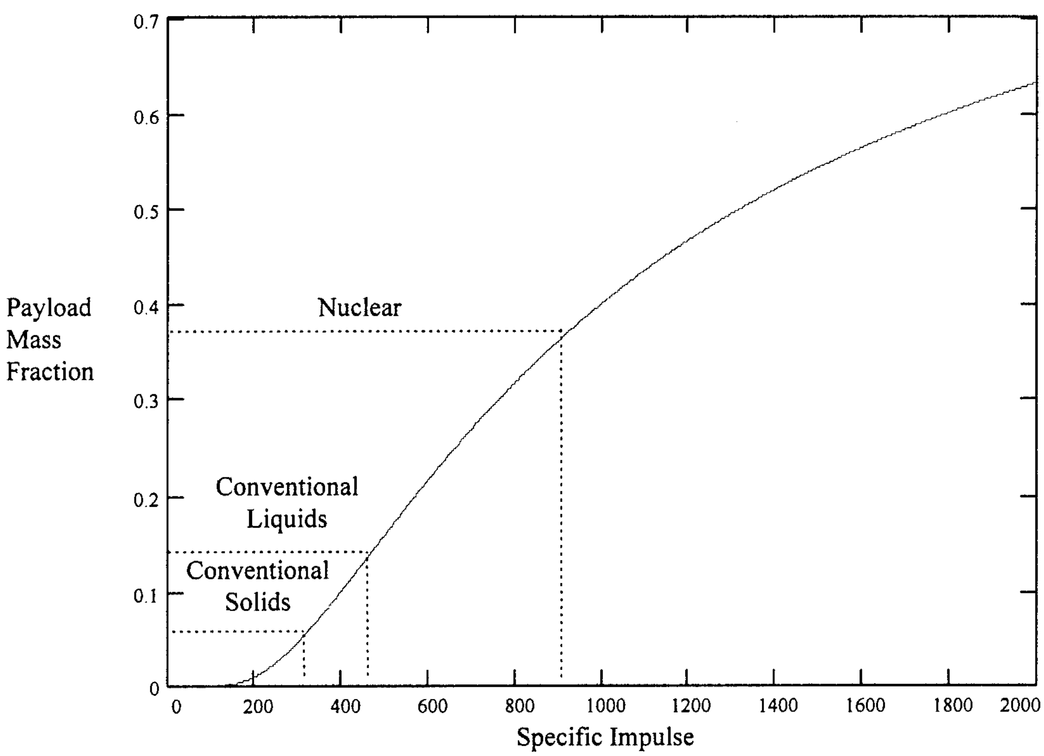


Figure 2. Payload Mass Fraction versus Specific Impulse[4]

The most promising near-term HEDM candidates are evolutionary improvements to the liquid hydrogen/oxygen propellant. These new propellants are based on additives to solid hydrogen and solid oxygen. For example, five percent addition of lithium boride (LiB) to solid hydrogen is projected to produce a 107-second improvement in specific

impulse. Addition of fifty percent ozone in a solid oxygen matrix is projected to improve the specific impulse by 25 seconds.

The HEDM program also has a revolutionary component. Revolutionary HEDM candidates are metastable monopropellants which might be decomposed yielding large amounts of energy. Calculations of molecular stability are being used to predict candidate metastable atomic arrangements expected to have very high energy content and practical lifetimes. For example, calculations by University of Georgia scientists suggest that dodecahedral nitrogen (N_{20}) may be metastable. A propulsion system based on the decomposition of N_{20} to diatomic nitrogen (N_2) could provide a specific impulse of about 500 seconds. Metallic molecular hydrogen is another proposed candidate. Experiments are being conducted to identify new high-pressure phases of hydrogen in hope of generating a hydrogen phase which might be metastable at lower pressures. A specific impulse of 1800 seconds for decomposition of metallic hydrogen represents the maximum theoretical specific impulse that can be achieved by chemical means.

The scientific challenges for HEDM are substantial. Candidate HEDM propellants have been proposed based on calculations of stability for novel atomic arrangements. Synthesis of even small amounts of these materials involves large scientific challenges. The probability of identifying a practical HEDM material by any experimental approach is highly uncertain. Until a promising HEDM candidate is identified through the use of computational techniques, the engineering challenges for producing the propellant in quantity or engineering a propulsion system to employ it are largely unknown.

Antimatter Propulsion[5]

Early in the HEDM program it was suggested that the enormous energy released from matter-antimatter annihilation might be useful for propulsion. In a simple picture, antiprotons and positrons would be slowed, trapped, and recombined to form a charged anti-hydrogen cluster. This antimatter cluster forms one part of a bipropellant fuel, the other being ordinary hydrogen. The antimatter cluster is then reacted with ordinary hydrogen and almost completely converted into energy.

The energy density of a propellant is linked to the characteristics of the reaction producing the energy release. Chemical reactions swap bond energies, with the energy

released being of the order of electron volts per reaction.[6] Nuclear reactions swap nuclear bond energies releasing energies of the order of millions of electron volts per reaction.[7] Similar to nuclear reactions, antimatter reactions swap rest mass energies, releasing energies of the order of a billion electron volts per reaction.[8]

The concept, in essence, is beautifully simple yet implementation eludes our current understanding and capabilities when we consider the requirements facing any high-energy-density fuel. Any HED fuel must be able to be economically produced in quantity, stored, reacted in a controlled manner, and permit efficient utilization of the energy released to directly or indirectly produce thrust. Antimatter fails each of these requirements. While very small amounts of antimatter would be required to provide the necessary heat source, current methods of producing and storing antiprotons provide trillions of times (12 orders of magnitude) less capability than what is needed.[9]

Even assuming that the host of difficulties associated with production and storage are surmountable, one faces the fundamental problem that the reactions themselves are extremely complex, and the products of the reaction include both high-energy radiation and elementary particles. These products are not terribly useful for propulsion since they are not easily converted to thrust (they are moving very fast and pass right through all but the heaviest materials without depositing their energy).

The environmental and safety concerns are similar to those associated with nuclear propulsion. Even if adequate shielding against the gamma radiation can be provided, temperatures will likely be so high as to require magnetic confinement to prevent meltdown of the reaction chamber.[10] From an operational standpoint, the failure of such a containment system will be catastrophic, resulting in a meltdown of the reactor and release of extremely radioactive by-products. Presently, there does not appear to be any way to make such a magnetic confinement system fail-safe. Therefore, antimatter propulsion systems and fusion reactors, which will also require magnetic confinement systems, were dropped from further consideration.

Nuclear Propulsion[11]

There are a variety of approaches to applying nuclear energy for space propulsion. In nuclear thermal propulsion, a propellant gas is heated as it flows through the core of a nuclear reactor and is then expanded and expelled through a rocket nozzle (see figure 3).

The reactor core can be a solid (e.g., uranium carbide particles in a graphite matrix or uranium nitride in a ceramic matrix), liquid, or a gas/plasma. The last two approaches can produce much higher propellant temperatures, resulting in higher specific impulse and greater rocket efficiency. Unfortunately, they are also significantly more challenging to realize since it is extremely difficult to flow a fuel through these reactors without expelling fissionable material in the exhaust. Therefore, this discussion will center on solid-core nuclear thermal propulsion.

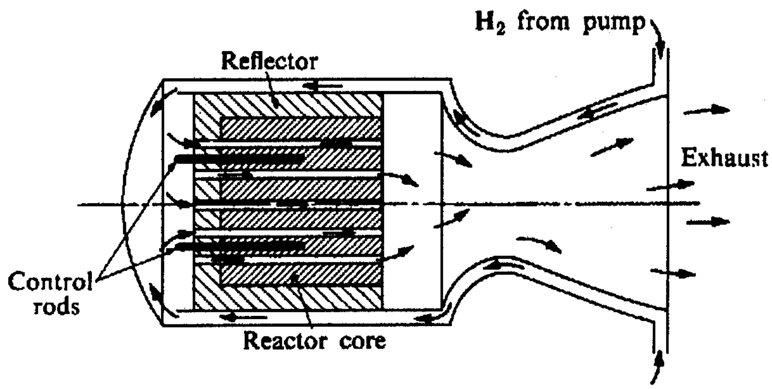


Figure 3. Solid-Core Nuclear Thermal Rocket Engine[12]

Project Rover started in 1955 at Los Alamos National Laboratory, with the goal of developing a solid-core nuclear thermal propulsion rocket using liquid hydrogen as both nozzle coolant and propellant. By 1967, a variety of systems had been developed and tested. The largest provided 200,000 pounds of thrust and was operated at full power for 12 minutes with a reactor system mass of 9,500 kg. Another design produced a specific impulse of 845 seconds.[13] While the program was deemed a technical success, changing national priorities resulted in cancellation of the program in 1973.

Solid-core nuclear thermal rockets have shown considerable technical promise. They can readily achieve specific impulses of 750 to 800 seconds and recent studies have suggested 875 to 900 seconds as goals. Dual-use designs have been proposed which will provide significant electric power from the reactor after the propulsion phase is complete. Furthermore, the proposed technology does not require advances in basic scientific knowledge.

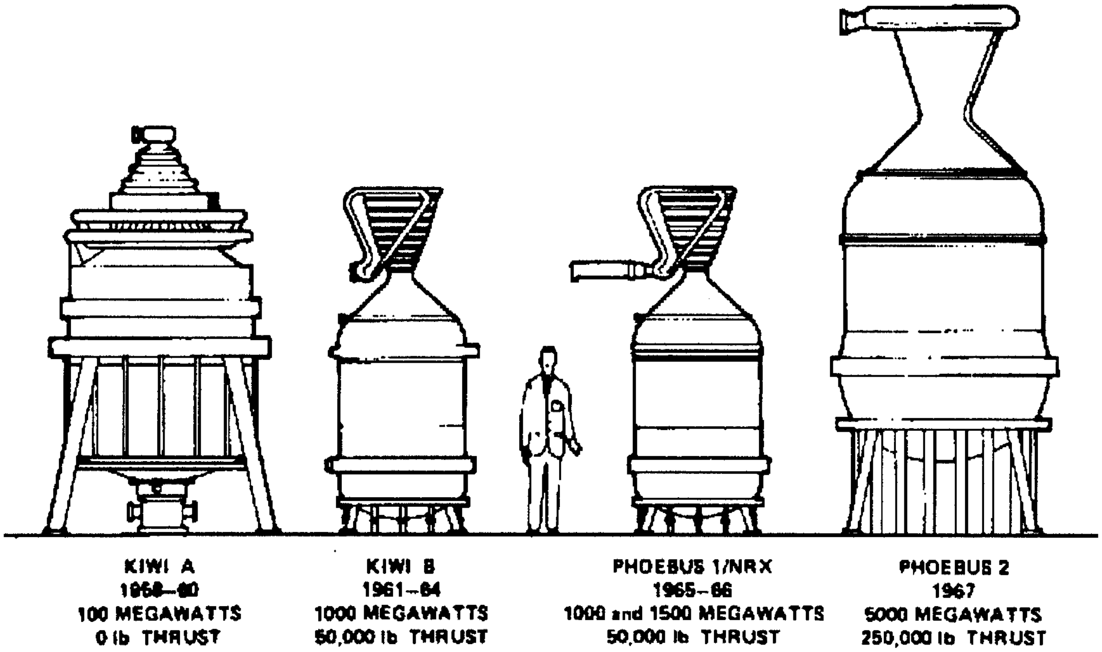


Figure 4. Project Rover Nuclear Rocket Engines[14]

However, some engineering problems nee to be overcome. The 1960s designs envisioned a nuclear rocket engine to be first powered up in Earth orbit for a planetary mission. They were not designed to launch payloads from the Earth's surface, but to operate in the vacuum of Earth orbit. Therefore, some design changes would be necessary. In particular, additional shielding will be required to block radiation emitted to the sides from backscattering off the atmosphere and into the payload. In addition, the Project Rover reactors suffered from fuel erosion in the core, due to the high-speed flow of hot hydrogen gas. Thus, the exhaust contained some uranium and fission products. Reduced fuel erosion can be obtained by using improved materials, thicker cladding, lower hydrogen temperatures, or a larger flow area (to reduce flow velocities). It should be noted that reducing or eliminating fuel erosion is necessary not to make the systems work, but to reduce or eliminate external contamination.

Uncontrolled reentry or launch failures will result in nuclear materials entering the environment, either intact, in pieces, or dispersed as fine particles. Placed in the context of other nuclear hazards, however, it will take thousands of launch failures to put as much fission product activity into the ocean as one sunken submarine reactor. It will take

hundreds of launch failures to put as much fission product activity into the atmosphere during an uncontrolled reentry as one of the smallest atmospheric nuclear tests.

Space nuclear propulsion could provide substantial advantages over conventional rocket propulsion. The technical risks are low and much of the work needed has already been done. The remaining problems are technical in nature; no scientific breakthroughs are required (the US does have experience with maintaining operational reactors by military personnel in its nuclear submarine fleet). Overall, the authentic environmental risks are modest. However, the problem very likely will be public acceptance. In a normal launch, a nuclear propulsion system will exhaust detectable, but not dangerous, radiation. In a launch accident, nuclear fuel and some fission products will be dispersed into the lower atmosphere as detectable, but not dangerous, particulates. To a society still regarding the detectable, but not dangerous, emissions from the Three-Mile Island accident as a 'disaster,' such emissions will likely be unacceptable.

Tethers

The most unusual concept examined was that of tethers.[15] Basically just a cable to space, an ideal design might be to run a cable through geostationary orbit all the way to the ground. With the center of mass of the tether orbiting with the same period as the rotation of the earth, it would sit stationary, much like the beanstalk in the fairy tale "Jack and the Beanstalk."

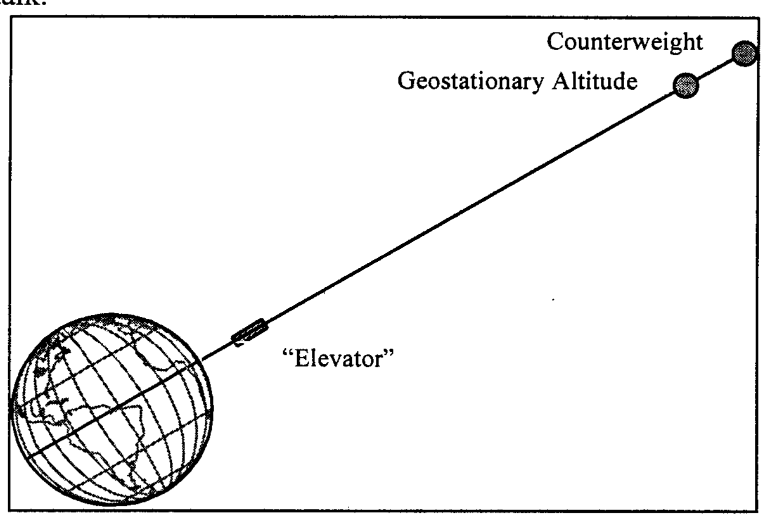


Figure 5. Geostationary Orbiting Tether "Elevator"

However, when examining current tensile strengths and densities of materials to construct such a tether, the mass required for such a project is on the order of a *trillion* kilograms--far exceeding our current manufacturing and spacelift capabilities. When examining the maximum possible tensile strengths theoretically achievable, the literature suggests that less than an order of magnitude improvement is possible in the strength-to-weight ratio of existing materials.

However, another design seems to have more potential. Instead of the extremely long tether envisioned in the previous concept, the center of mass of the tether is placed in a much lower orbit. If the tether were to simply dangle into the atmosphere from this orbit, however, it would have a hypersonic passage causing considerable drag and eventually pulling the tether from orbit. If, instead, the tether is counter-rotated so that as the lower end of the tether passes through the atmosphere it is traveling at sub-sonic speeds, the drag is reduced considerably, as is the amount of time the tether is subjected to this drag. A space launch vehicle can now be flown up to rendezvous with the end of the tether. The tether would be long enough to allow the appropriate atmospheric velocity and to reduce the centrifugal acceleration on injection into orbit. Such a tether would extend approximately 2,200 kilometers from the center of mass and would reach down to 12 kilometers above the earth's surface. Orbital altitude and angular momentum could be maintained by the use of high-efficiency, low-thrust engines (e.g., solar-powered ion or electrodynamic engines).

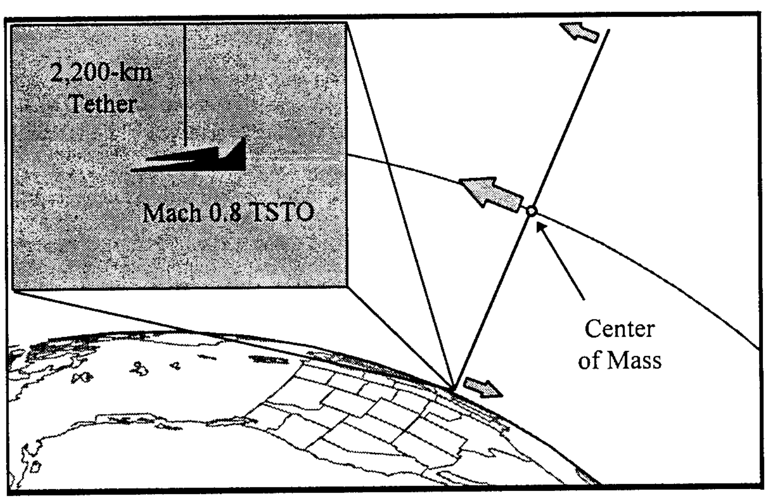


Figure 5. Rotating Tether

While the tether concept is conceptually simple, the construction and practical operation of such a system is filled with engineering challenges. Tether fabrication and deployment, characterization of its dynamic behavior, and development of techniques for successful docking represent a few of these challenges.

Recommendations

Based upon the results of this study, the following recommendations concerning high-leverage technologies supporting unconventional launch concepts are made:

- Research into high-energy-density fuels has the highest potential for payoff. Expansion of current technology development programs in this area should be a top priority.
- Research into advanced high-strength-to-weight materials benefits not only the construction of future tether systems but also the development of lighter, more durable spacecraft. Expansion of current materials development programs should also be a high priority.
- Research into nuclear engine design for launching payloads to low-earth orbit should be initiated.
- Research into the dynamics and design of tether systems should be continued.

THE SPACELIFT PROBLEM[16]

(ATTACHMENT)

The Problem

The fundamental problems facing our nation's ability to conduct routine space operations are the high cost and excessive delays now associated with conducting launch operations. Current information shows that it costs between $4,500 and $6,500 a pound to reach low-earth orbit (table 1). Furthermore, these numbers *only* reflect the price charged directly to the customer.

Launch Vehicle	Lift Capability (100 NM 28.5°)	Launch Price	Cost per Pound
Pegasus	1,000 lb	$7-$12 M	$7,000-$12,000
Taurus	3,200 lb	$15 M	$4,690
Titan II	5,000 lb	$43 M	$8,530
Delta 7925	11,100 lb	$45-$50 M	$4,050-$4,500
Atlas II	14,100 lb	$70-$80 M	$4,960-$5,670
Atlas IIA	14,900 lb	$80-$90 M	$5,370-$6,040
Atlas IIAS	18,500 lb	$110-$120 M	$5,950-$6,490
Titan IV	39,000 lb	$154 M	$3,950
Shuttle	51,800 lb	$130-$245 M	$2,510-$4,730

Table 1. Cost per Pound to LEO for Active US Launch Vehicles[17]

Recurring costs for the manpower required to launch the current US inventory of launch vehicles and the associated costs of operating our launch bases (table 2),

Launch Vehicle	Manpower Costs
Taurus	$100,000
Delta 7925	$3.3 M
Atlas II	$7.9 M
Titan IV	$48.0 M
Shuttle	$30-$84 M
Launch Sites	
Cape Canaveral AFS	$1.32 B/year
Kennedy Space Center	$2.16 B/year

Table 2. Manpower Costs[18]

suggest that the advertised prices for launch services do not cover recurring costs, much less amortize investment in R&D and infrastructure.

Launch Vehicle	Advertised Time to Launch	8-Hour Shifts
Pegasus	2 days	18
Taurus	5 days	Unknown
Delta 7925	23 days	102
Atlas II	55 days	115
Titan IV	100 days	190
Shuttle	150 days	240

Table 3. Launch Times

So, with launch services priced as they are, satellites must be built with the utmost in reliability, further driving up costs. The process of continual optimization and testing to ensure success drives up costs and drags out production schedules.

Schedules for preparing current launch vehicles and their payloads result in considerable delays in getting vital national assets on orbit (table 3). In many ways, the launch facility is the remote extension of the manufacturing facility. The product is not "finished" until pre-launch processing is complete. Not only do delays occur in launch processing, due primarily to a lack of standardized procedures, but they also occur in development due to the continual need for optimization. Since these systems are built to operate at maximum performance, safety margins are slim, causing further delays to improve the odds of success. All of these delays are major obstacles to the successful conduct of both military and commercial routine operations in space.

The need for timely assured access to space is particularly critical in the military arena. As the US moves into the next century, it will surely not be the only space power. Should it become embroiled in a conflict with another space power which leads to the destruction of on-orbit assets, the side which can reconstitute the capability derived from its lost assets the quickest will prevail. Even if the US does not go up against another space adversary, the current proliferation of nuclear weapons and ballistic missile technology makes it easy for an enemy, with no space assets to lose, to strike at and cripple near-Earth satellites with the launch of a single, unguided nuclear weapon. Furthermore, the expensive and unique launch infrastructure which currently limits US

dispersion of launch resources to two launch bases, makes them extremely vulnerable to enemy attack, including terrorist attack. (Natural disasters, such as hurricanes or earthquakes, are other obvious risks to the launch infrastructure.)

There is an economic threat, as well. Since 1976, the US share of the commercial launch market has dropped from 100 percent to about 25 percent.[19] European, Russian, and Chinese launch prices are currently set at about half of what US launch services are. If the US is to remain competitive in this market, it *must* reduce launch prices considerably. The market is waiting to explode should a substantial drop in the price of launch services be realized, as evidenced by the recent announcement by the CEOs of Microsoft and McCaw Cellular Communications to deploy a network of 840 satellites to provide a global Internet.

Cost Considerations

Costs for operating any venture consist of fixed costs (one-time expenditures which do not change with changes in activity) and recurring costs (expenditures which vary based upon the activity level). To remain viable, a venture must cover recurring costs and amortize fixed costs over some reasonable period of time. For high-volume operations (such as the airlines), the key to profitability is to reduce recurring costs. For any operation, reducing fixed costs as a percentage of total operating costs is imperative, whether by reducing overall infrastructure or increasing the volume of operations.

To reduce costs in launch operations, any solution must have the goal of reducing the expensive, unique plant and equipment (e.g., launch processing facilities, extensive real estate holdings, and launch pads) together with the very large numbers of people required to maintain them. Recurring costs must also be reduced, particularly if spacelift operations are ever to be conducted anything like airlift operations.

Briefly contrasting current spacelift operations to airlift operations suggests that if airlift operations were conducted in the same manner as spacelift operations, each mission would begin with planning to determine payload characteristics well in advance of launch. The aircraft, which would be late-1950s vintage, would be selected to optimize performance based upon this payload, wasting as little performance margin as possible. Once the parts of the aircraft arrived at the airport, they would be wheeled out on the runway, one of the most expensive pieces of infrastructure, where the major

components of the aircraft would be assembled and then the payload would be loaded. Since each operation is different, ground crews would have to improvise procedures for each takeoff. Because of the limited performance margins, any adverse weather conditions would delay takeoff. In the meantime, no other aircraft could takeoff or land on the runway. Once the aircraft was finally launched and delivered its payload, it would be scrapped.

When juxtaposed in this fashion, it is clear that this approach is severely flawed and in need of major changes. How did this situation result? Primarily because the US failed to make the same kinds of investments in developing safe, reliable, easy-to-use, reusable spacecraft that it did with aircraft. Instead, the US apparently has been content to continue using 40-year-old technology and proposing to use it for decades into the future. While some may judge these observations as unkind, they do not appear to be inaccurate.

So, how can these problems be resolved? Any solution solving the overall problem of reducing cost per pound to orbit must reduce recurring costs (use reusable launch vehicles) and eliminate or significantly reduce overall plant, equipment, and manpower costs. The latter can be done by standardizing and automating operations (thus reducing manpower) and *designing* the launch vehicle to operate from an existing infrastructure (such as the plant and equipment available at airports worldwide). This last point is crucial, since it will no more be politically or economically feasible to build special airports for a new aircraft than it will a new launch infrastructure for a new spacecraft. As can easily be seen, these are requirements that must be "built in" from the beginning.

Timeliness can also be improved by *designing* the launch system to be 'operational,' as well as designing in wider safety (performance) margins, thereby permitting launch under a broader range of conditions; and wider safety margins reduce overall development costs by reducing the need for extensive testing.

The US must push for fundamental changes in the way it conducts launch operations. Whatever it chooses to build must be simple to build and to operate. As noted in USSPACECOM Pamphlet 2-1, "In space warfare, as in all forms of warfare, the application of simplicity requires that plans conceived by geniuses must be executable by personnel who are not."[20] Therefore, any new system must be *designed* for automobile-

type production and airline-type operations--either of which is capable of being performed by an average skilled technician. The goal for military space operations is to design systems and procedures so that launch vehicles can be maintained by well-trained high school graduates and operated by well-trained, non-scientific college graduates. Failing this, routine space operations remain an elusive goal.

Notes

[1] Fusion and antimatter also fall in this category.
[2] George P. Sutton, *Rocket Propulsion Elements: An Introduction to the Engineering of Rockets*, New York: John Wiley & Sons, Inc., 1992 (Sixth Edition), p. 36.
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RAPID SPACE FORCE RECONSTITUTION (RASFOR)

Subject Summary

A rapid space force reconstitution (RASFOR) operational concept using rapid-response spacelift and light satellites (lightsats) is presented. Its focus is directed at immediate development and acquisition actions necessary to meet the requirements of the world of 2020 and beyond. RASFOR directly complies with two of the foundations of the US National Military Strategy--crisis response and reconstitution--which in turn have direct traceability to the grand strategy of the United States. Future conflicts will require more responsive military forces which are increasingly dependent on space assets to support their operations. They may be pitted against adversaries also having military space assets, giving challenge to our space systems during military operations. The proliferation of space technology may allow future adversaries to degrade or destroy our satellites. Also, unanticipated system failures and multiple area coverage requirements may require the immediate placement of satellites into orbit. To meet these challenges, RASFOR is essential to space operations--it can provide the space support tasks necessary to meet joint requirements in the future combat environment. Although alternative operational concepts exist (status quo launch, on-orbit storage, and repositioning), they are inferior to RASFOR.

Current spacelift assets cannot provide the support necessary to reconstitute critical force-enhancing satellites in a combat environment. One of the pitfalls of previous spacelift studies has been that participants have all had "back pocket" agendas to sponsor specific systems. To avoid this parochialism, this paper does not propose specific systems to solve our combat deficiencies in space, but rather, it provides a vision toward the solution.

Problem Statement

Is there a need for a rapid space force reconstitution capability to meet US military combat support requirements of the future? There are many situations that may challenge our existing satellites and require their replacement or augmentation. No matter how well designed and built a satellite is, it is still subject to the random failure of

components (i.e., not involving actions by hostile forces) which may render subsystems, or the entire system, useless. External environmental conditions (e.g., micrometeors, solar flares) may contribute to these failures. If such a failure occurs on a satellite critical to ongoing military operations, it may be necessary to replace it immediately.

Shared Satellites

The "global reach" of US forces may require deployment to geographic areas not covered by existing space assets. Even though certain satellites have limited maneuver capabilities, it may not always be possible or practical to move satellites to cover deployment areas. A satellite may need to be placed in a unique orbit to cover the theater of operations.

If the US becomes involved in two conflicts at the same time, existing space assets may not be able to support both theaters. If the theaters are too close together, then they may have to share satellites--their demands may saturate or overload existing satellite capabilities. If the theaters are far apart, then they may compete for limited satellites. In either case, the integration and coordination of limited space assets can only add to the friction and fog of the operations. The solution is obvious, but not simple--put up adequate satellites to support *both* theaters.

Interference with Satellite Operations

In future conflict, the US cannot afford to assume our space assets will not be interfered with. Future planners may need to factor in satellite attrition, just as ground and air forces attrition is included in today's planning.[1] The former Soviet Union has demonstrated several types of anti-satellite (ASAT) technology,[2] and it is reasonable to predict this technology will be available to future aggressor nations.[3] The US strategy of fielding low quantities of high-quality satellites creates "an over-concentration of US assets in a limited number of necessarily costly satellites [which] provides inviting targets, contributing to an increased threat."[4] A satellite will probably not be "taken out" by an ASAT weapon unless hostilities are occurring, and the aggressor will probably only target satellites critical to the ongoing conflict. To maintain space support for the war fighter, the satellite will have to be replaced immediately.

Counter-Space Operations

Just as we must ensure US use of space, we must plan to deny use to any adversary (space control). Certain types of counter-space weapons employed by the US may need to be placed into orbit (or replenished) during hostilities. Part of the principles of the Air Force's contribution to national security is that "space superiority is joining air superiority as a *sine qua non* of global reach and power."[5] However, space superiority cannot be achieved unless the US can overcome the operational demands presented above.

Meeting the Challenges: RASFOR

The challenges facing space systems in the future all point to the need for RASFOR as an essential element of future combat forces. General John Piotrowski, former commander in chief of USSPACECOM stated that the US "must be capable of *reconstituting* degraded or destroyed spacecraft *on demand*."[6] Our current launch tools can meet peacetime requirements, but they are "much too slow to meet the demands of combat."[7]

A Proven and Recognized Solution

The use of RASFOR was clearly demonstrated during the Falklands War. Within a 69 day period of the war, the Soviet Union conducted 29 satellite launches--an extraordinary surge capability.[8] In contrast, US emergency launch times must be measured in months rather than days. As an example, consider the failure of a Defense Meteorological Satellite Program (DMSP) satellite on 3 September 1987. On 13 October 1987, an emergency launch call was issued, a DMSP replacement was "urgently needed." The replacement satellite was launched 3 February 1988--113 days after the emergency call and 153 days after the failure.[9] In the future, it is likely that a major regional conflict can be fought and won (or lost) in much less than 153 days.[10]

Limitations of Existing Reconstitution

During Operation DESERT STORM, a military satellite was moved from Pacific Ocean coverage to Indian Ocean coverage to augment communications capacity in the

theater. It was the first time a department of defense (DoD) satellite had been repositioned to support US combat operations. Although this action fulfilled a combat support requirement, the continued approach of reconstitution through on-orbit storage and repositioning is flawed.[11]

The concept of the on-orbit storage of spare satellites (prepositioning) makes the spares as vulnerable as the active satellites. Enemy space forces can monitor and selectively target critical satellites and take them out at once. Storing spare satellites on orbit also uses up a portion of their useful life through exposure to the harsh space environment and the use of limited expendables (e.g., fuel for station keeping). Repositioning maneuvers also expend limited fuel resources; in certain cases, the required orbital changes may be so great and the available fuel so limited that the repositioning maneuver is not physically possible. Further, when a satellite is moved to a new area, it will weaken (or eliminate) the support in the old area. Finally, repositioning is not an instantaneous event. If a responsive spacelift capability is available, there may be certain cases when it will take less time to launch a new satellite (using RASFOR) than it will to reposition an existing one.

RASFOR Concept

The development of rapid-response spacelift can fundamentally change US space operations, but only if it is coupled with a parallel change from complex, heavy, long-life satellites to simpler, smaller, shorter-life satellites called lightsats. In war fighting terms, the big satellites are like B-17s in space--self-defending, capable, and an easy target for a determined foe. In contrast, the use of lightsats coupled with a rapid-response spacelift system could dramatically increase space combat capability. This combination of systems--rapid-response spacelift and lightsats--are the *force elements* necessary to accomplish RASFOR.

The operational concept for RASFOR is illustrated in figure 1, which outlines the actions supporting commands (US Space Command and individual service space commands) must take to provide RASFOR.[12] When space support is requested by a combatant commander (COCOM), the supporting command will observe existing space assets, assess their ability to meet the COCOM needs, and decide if RASFOR is required. Once the decision is made to use RASFOR, the supporting commands will prepare and execute the mission: launch the rapid-response spacelift vehicle, orbit the lightsat,

perform on-orbit checkout, and finally, task the lightsat. During the RASFOR mission, the supporting commands will also perform dynamic engagement control functions, such as range tracking and control.

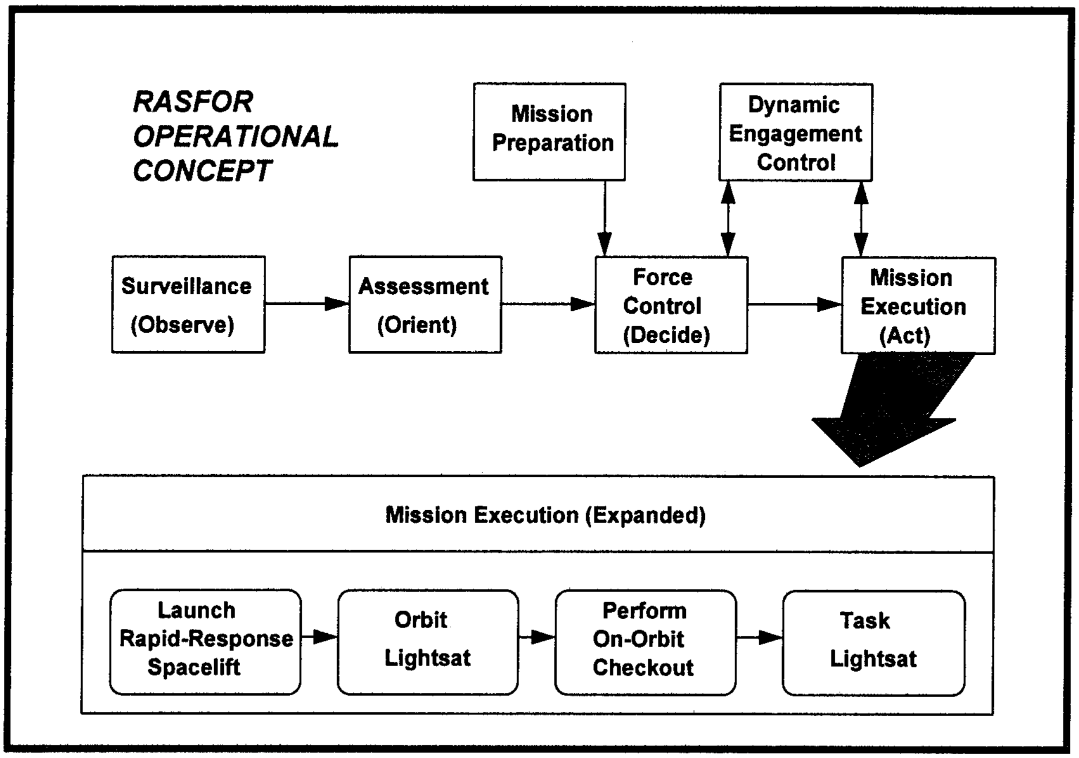

Figure 1. Rapid Space Force Reconstitution Operational Concept

Historical Background

Intercontinental Ballistic Missile (ICBM) Heritage

One of the major problems with our current space launch vehicles (SLVs) is that most of them are derivatives of ballistic missiles--they were never designed to deliver satellites to orbit. For the most part, these SLVs are based on 30 to 40 year-old technology.[13] These ICBM core vehicles evolved over the years, primarily in response to growing payload requirements.[14] The expense of spacelift helped to fuel a vicious cycle for satellites design. First, high development and launch costs led to the procurement of high quality (long life) satellites in low quantities. In turn, the requirement for long satellite life led to

numerous reliability design features, including subsystem redundancies, adding complexity and weight to the satellite. This added weight required more performance from the SLV, which in turn drove up the spacelift costs. The increased spacelift cost brings us full circle back to the need for high quality satellites.

Although the booster community delivered incremental performance increases for their satellite customers, today's SLVs have only undergone one, possibly two, generations of evolution since the late 1950s. In contrast, jet fighter aircraft have undergone five generations from the F-86 to the F-22,[15] and stealth technology has also undergone five generations.[16] Lt Gen Moorman, vice commander of Air Force Space Command, stated "the space community is launching the equivalent of the F-4 series fighter into space" and advised that "space launchers need the same relative modernization that our modern-day fighters have had."[17] There has never been a "clean sheet" design for an operational military SLV; in fact, the Saturn V and the Space Shuttle represent the only US spacelift vehicles designed "from scratch."[18]

Reactive Approach

In the past, the US has often waited until it perceived a *severe* threat--a crisis--before it acted. The resulting actions involved sudden major investment and effort to overcome the threat. To accomplish this de facto strategy, the US relies heavily on technological surges rather than consistent and incremental improvements.[19]

Implications

Simply put, US spacelift has not been put to the war-fighting test yet. Although US forces relied upon satellite-based force enhancement during the Gulf War, there was never a threat to these satellites which required rapid reconstitution. Of the four combat media--land, sea, air, and space--only in space has the US *consciously allowed itself to be inferior in war-fighting capability.* Maj Gen Robert Rankine, former vice commander of Air Force Space Division stated "our capability to accomplish *force enhancement* from space is superior to that of the Soviets--but only during hostilities that do not place the satellites themselves under attack."[20] Another senior DoD official noted "the Soviet Union is superior in the war fighting aspects of the launch infrastructure."[21] Since there has been no need for the rapid reconstitution of satellites in combat, there has been no effort toward RASFOR development.

Reconstitution must be accomplished in a timely manner if it is to provide the force enhancement when needed. The current published doctrine concerning the deployment of space forces (Air Force Manual 1-1) confirms this:

> Rapid-response spacelift must be available to emplace and replace critical space assets. The US military relies extensively on space assets for many critical missions. In a crisis, it may be necessary to concentrate assets quickly. Failure of these assets or their destruction by enemy action could lead to disastrous consequences unless they can be quickly replaced.[22]

In 1992, a comprehensive Blue Ribbon Review of Air Force space policy, organization, and infrastructure was conducted. One of its key findings states: "In the future, the need for space support in major conflicts will likely exceed peacetime capabilities in terms of capacity, interoperability and flexibility."[23] This points to the need for spacelift that is not only responsive, but is also capable of rates and volumes greater than normal peacetime operations.

To have a superior warfighting space force, we must be able to place satellites into orbit *when and where we want to*--we must have control over the space lines of communication. A key element of this control is access, making a rapid-response spacelift system an essential element of future combat forces.

Consensus Building: The Case of the Space Shuttle

One of the political challenges facing RASFOR is that the development of its spacelift element may require the consensus of numerous space agencies. This process, which is difficult even within individual agencies, is time consuming, and it often forces unfavorable compromises. A review of the decision-making process during the Space Shuttle development noted:

> While one of the long term strengths of the American system has been a willingness to make pragmatic compromises to achieve results acceptable to the widest range of viewpoints, in a heavily technological arena such an approach was of questionable virtue.[24]

Indeed, the topic of spacelift has been over-studied since the *Challenger* disaster, with no consistent national launch strategy being developed, let alone a definite decision to pursue the rapid-response spacelift capability required for RASFOR.

While a detailed case study of the space shuttle, or space transportation system (STS), is beyond the scope of this paper, a brief review of some of its political problems is germane to RASFOR. After all, the STS was originally conceived as a rapid-response spacelift system, capable of 2-week flight turnarounds and 25 or more missions per year using 5 reusable orbiters.[25] However, after running through numerous political wickets, the final product bore little resemblance to the original concept.

When funds were reduced under the Nixon Administration, the National Aeronautics and Space Administration (NASA) tried to gain support "on a cost-effective, rather than on scientific, technological, or other grounds."[26] This strategy was a mistake made by "government bureaucrats who played the political game and sold the Shuttle as an inexpensive program, in the process sowing the seeds of disaster."[27] During development, the STS was kept alive through a forced marriage between NASA and DoD mandated by President Carter. This arrangement forced a dramatic change in STS configuration and mission profile increasing program costs.[28] This also resulted in sole reliance on the STS for US heavy spacelift--the US had all of its space-access eggs in one basket. Following the *Challenger* accident, the resulting spacelift crisis led to the rapid reinstatement and modification of four classes of expendable SLVs.[29] The final assessment of the STS, made by the Vice President's Space Policy Advisory Board in November 1992, was that "the Shuttle is very expensive relative to its role in the US space program." This expense is listed at about $5 billion per year to support only seven or eight flights per year[30] --over $700 million per flight (many analysts list this cost even higher). The cost of the most expensive of the "crisis response" replacement SLV programs, the Titan IV, is listed as at least $350 million per launch.[31]

Design Approach

Long Life of Satellites

The primary reason why the US has not pursued RASFOR has its roots in the US design approach to spacecraft. Unlike the former Soviet Union (FSU), the US has always

stressed *quality* over *quantity*. US satellites are designed to have long service lives, with the strategy being to *endure,* whereas the FSU strategy has been to *surge* using its robust spacelift capability. US satellites are also designed to be more capable, which required the FSU to have more satellites in their constellations to do the same job. The resulting high satellite replacement rate forced the FSU to develop a spacelift infrastructure capable of launching five times more frequently than the US.[32] Historically, many US satellites' lives exceed prediction, thereby allowing a launch-on-schedule strategy to build up assets in space.[33] Because of this, there has been no drive to make RASFOR a reality.

Research and Development Approach

In addition to their ever-increasing performance requirements, the satellite community has also made demands on the physical configuration of the boosters. Payload interfaces, shrouds, and pyrotechnic devices have at times varied greatly from launch to launch. Since these engineering changes can only be flight-validated during an actual launch, many SLV flights become research and development (R&D) milestones.[34]

This R&D approach often resembles the 1950s b-movies, where space launches are performed by groups of scientists in white lab coats. It is in sharp contrast to the normal concept of military operations, in which the standardization of training and procedures are paramount. There is limited standardization in the assembly and checkout of boosters, and even less during payload processing.[35] In many cases, special test and support equipment is required for launch preparations. Personnel training is also a challenge, because the procedures on which an operator becomes qualified on one launch may change for the next launch.

This R&D approach to spacelift has at least four negative operational impacts: reduced error margin, increased support requirements, increased processing times, and increased operating costs. The R&D methodology often pushes the design limits of the vehicle, thus reducing its margin for error.[36] New "black boxes" and increased thrust requirements may put vehicles at the edge of their performance capabilities, making each launch very risky. To help reduce this risk, an elaborate vehicle processing support network is used. This network often requires unique test equipment and procedures, and it is usually manned by an army of contractor engineers and technicians. In addition, a contingent of government workers is required to plan and monitor the processing. This methodical, "check everything twice" approach may reduce risk, but it does so at great

cost to schedule. Procedures written at a contractors facility may not work at the launch pad, making "redlines" and workarounds common. Lack of standard test software also contributes to increased processing times. The need for unique support equipment and procedures, highly-qualified personnel, and long processing schedules results in high operating costs for each launch.

Cost

One of the greatest challenges facing the military today is the reduced budgets under which it must operate. This is reflected in the current DoD space investment strategy, which has a fundamental goal "to make future DoD space systems more cost effective while retaining US technological superiority." It emphasizes "reduced procurement and life-cycle costs consistent with operational requirements,"[37] but follows the paradigm that the technological superiority will satisfy operational requirements. This misguided approach has led DoD to continue the evolutionary process of spacelift; in essence, a decision to throw good money after bad. This is not a temporary measure; the decision will extend life of the current launch vehicle fleet to the year 2030[38] -- banking on many subsystems embodying *sixty- year-old* technology.

The problem with this proposed strategy is that it ignores other elements of cost. In choosing the status quo approach to spacelift, DoD is sentencing spacelift to remain non-responsive and manpower-intensive into the twenty-first century. An old Chinese proverb says: "Where there is no gain, the loss is obvious."[39] If US military spacelift remains the same while others proliferate, how can we do anything but lose? Economists refer to "opportunity cost" as the cost of selecting a given approach and the resulting benefits foregone by not using the best alternative.[40] Unfortunately, the opportunity costs of this decision may be the loss of US lives during conflicts with enemies having war-fighting capabilities in space. To avoid this, current and future studies concerning spacelift costs, especially those that make cost "the primary measure of merit,"[41] must address the opportunity costs faced by peace-time systems in a combat environment.

Developing and implementing RASFOR systems will not be cheap, however, these systems can help to lower spacelift costs. By nature of its requirements, the rapid-response spacelift element will have increased reliability to avoid costly losses. This increased reliability, along with a possible in-flight abort capability, can reduce range

safety requirements and costs. Also, a RASFOR system with reduced infrastructure and standardized procedures will have lower operating and manning costs.

Most importantly, RASFOR provides a way to break away from "business as usual" by introducing a fundamental change in the way the US designs satellites. If satellites can be launched rapidly, consistently, and reliably, then the dependence on long-life satellites no longer makes sense. In fact, RASFOR will allow new technology to be implemented faster, since the time between satellite design generations will decrease, and the overbearing emphasis on reliability can be eased. This will result in smaller and more capable systems with shorter lives.[42]

Technological Feasibility

As previously mentioned, the FSU demonstrated effective RASFOR during the Falklands War. Their system, previously assumed to be crude by US standards, clearly demonstrates that technology is *not* a barrier to RASFOR development. While existing technologies may suffice, existing systems do not. To approach RASFOR development as the modification of existing SLVs will be a mistake. The entire system--launch vehicle, payload interface, infrastructure, launch operations, personnel, etc.--must be approached in a "clean slate" manner. There are many examples of spacelift systems with RASFOR characteristics; these systems range in maturity from conceptual to operational. It is not the purpose of this paper to advocate any specific technical solution; therefore, these systems will not be discussed.[43]

A Spacelift Panacea?

Will RASFOR cure all the ills of spacelift? No. Rapid response is not required for all launches; a routine (versus urgent) launch on need should apply to most launches. RASFOR systems may also have payload weight limitations (such as the support equipment needed for manned space flight) preventing its use for heavy spacelift. To be cost effective, a separate class of newly-designed medium and heavy lift SLVs should also be pursued to provide a flexible spacelift capability.

Evolution Versus Revolution

As previously discussed, our current military spacelift vehicles have evolved for over 30 years from their ICBM roots. This evolutionary approach has developed well beyond the point of diminishing return, requiring great expense for incremental performance increase. This continued pursuit of "one more modification" is a cancer upon our nation's space force, with a tremendous appetite for resources which when fed, only makes the system weaker. It is time to break this vicious cycle.

A more radical approach to spacelift is to pursue exotic technologies offering revolutionary performance increases. Anti-matter, anti-gravity, electromagnetic, and other such propulsion technologies may be available in the distant future. However, existing spacelift deficiencies require immediate attention if we are to provide combat space support to war fighters. Neither the evolutionary nor the revolutionary approach can resolve spacelift deficiencies; a new approach is required. However, before presenting this new approach, it is important to examine a key misconception within the current view of US military space.

The Misconception: Technology and Capability

We have an illusion of superiority, thinking that superior technology equates to superior combat capability. Indeed, an August 1993 White Paper from US Space Command stated that "It's important that the US maintain its superior space capabilities."[44] Unfortunately, the paper didn't address the circumstances under which the *asserted* superiority exists. The future environment of space operations may be that of a shooting war. A better approach, then, is to state: It's important that the US *develop* superior *war fighting* space capabilities.

The De-Evolution of Spacelift--A Paradigm Shift

The primary problem with our current spacelift system is that it ignores a fundamental truth--*no one can build a perfect system.* Murphy's Law will always apply, and during war it will be augmented by Clausewitzian fog and friction. Our current spacelift operations seem to embody the belief that if enough money, studies, people, and quality assurance are thrown at a system, it will become perfect. However, this approach overlooks another fundamental truth--a system doesn't need to be perfect if it is designed

to be *robust and fault-tolerant.* Applying these two truths to our spacelift shortfalls points to a solution away from our current systems and toward the technologically "inferior" systems of the former Soviet Union (FSU):

> If the Soviets use technology that is primitive by our standards but meet their mission requirements while we fail to satisfy ours, then their technology is better by any sensible standard of military utility. In fact, if the cruder Soviet system allows greater latitude for error and thereby yields greater reliability, then for all practical purposes it is a better system.[45]

This backing away from current razor-thin, high-technology design margins to the robust "duct tape it before launch" approach of the FSU[46] represents a significant paradigm shift--a "de-evolution"[47] of technology required to increase *operational utility.* This approach can lead to a rapid-response spacelift system emphasizing standardized procedures, short sortie generation times, robust design margins, and simplified launch site operations.

This is not to say advances in technology are bad. However, the application of these advances must be balanced against *operational utility* and *design margin.* Just because a system can be designed within one percent of structural failure doesn't mean it has to operate that way. Engineers may need to throw away their complex computational fluid dynamics design software and learn to use a slide rule again--the point being that common sense and intuition should be emphasized over blind faith in computer simulations. Technicians and maintenance personnel should also have a say in the design process to help reduce complexity of operations.

System versus Vehicle Approach

The primary goal of the de-evolution approach to RASFOR is to emphasize operational utility in the design of the *system.* While specifications may accomplish this, they often miss the "big picture" by getting lost in the specific details of the vehicle. The development of the F-111 aircraft is a good example. Although it is now a very capable weapon system, strict adherence to arbitrary design specifications needlessly drove up development costs and delayed its schedule. If the overall mission and concept of the F-111 system were more clearly stated and followed, many of these specifications would have been reconsidered to the benefit of the program.[48]

Similarly, in developing RASFOR, the entire system must be considered. Even if a vehicle can be developed to launch in hours, it is of little use if it takes months to assemble, checkout, or emplace at its launch facility. Taking it one step further, the operational ends of RASFOR are worthless if the satellite it carries takes a long time to check out on orbit. The use of lightsats, with fewer subsystems and lesser mass, can dramatically reduce the time required for on-orbit operations.

Risk Reduction versus Risk Distribution

Under the evolutionary approach to space operations, risk reduction was accomplished by tedious quality assurance checks and extensive system redundancies. One of the greatest benefits of a RASFOR approach is operational risk is distributed--the dilemma of having all the eggs in one basket is avoided. This concept of risk distribution can prevent the recurrence of previous billion-dollar losses, such as the Titan IV SLV incident of August 1993.[49] Also, this concept will drastically reduce the need for quality checks and redundancies, thereby reducing procurement and operating costs.

Simplicity

In pursuing a RASFOR system, simplicity must be emphasized to avoid the pitfalls of complicated evolutionary systems. Simplicity of equipment and operations can significantly increase the utility of spacelift. Specific methods to reduce system complexity include the standardization of equipment and procedures. Boosters and satellites can be developed with common modular elements and standard interfaces. These measures will reduce costs of procurement by introducing larger production buys with fewer configuration changes.[50] Repeatable procedures can reduce training requirements and reduce the chance for error.

A major contributor to the complexity of current systems is infrastructure, which includes many elements: transportation, handling, and test equipment; storage, assembly, and launch and facilities; and command, control, and range operations centers. These required elements not only complicate spacelift system operations, but they also carry their own logistics and maintenance problems. During RASFOR system design, a conscientious effort should be made to make maximum use of existing military infrastructure, thus reducing the need for specialized equipment. Simpler systems with

less infrastructure can also reduce the manpower required for operations, thus saving costs and reducing the chance of human error causing the system to fail.

The Proper Use of Technology

The purpose of this paper is not to bash technology, nor is it to make light of the tremendous accomplishments of our national space programs. However, it is intended to warn against the US resting on its space laurels. We cannot continue to contend that, during war, our advanced technological capabilities and industrial base can make up for short-sighted strategic plans made during peace. During the development of RASFOR, technology must be seen in its proper light--as a *possible means* to a solution, *not* the solution itself. The technology offering the greatest simplicity and operational capability must be selected, even if it is not the most "advanced" of choices.

One of the most promising advances of the next decade fit well to the RASFOR approach--microtechnology. NASA's Jet Propulsion Laboratory had already been able to reduce the size of a certain transducer from the size of a soda can to a mere cubic millimeter. Not only does the microtechnology save weight, space, and power, but in some cases it may provide instruments that are actually more sensitive than their larger predecessors.[51]

Military First

Contrary to the recommendations of numerous spacelift studies having been conducted since the *Challenger* disaster, combat capable space systems should be pursued without the influence of civil and commercial interests. While civil and commercial space programs entail large expenditures, they represented only 0.24 percent of the 1992 gross domestic product[52] --hardly a threat to US economic viability. In contrast, existing and proliferating foreign military space capabilities present a feasible threat to US national security. This is not to say civil and commercial space industry cannot benefit from the more capable military systems produced through de-evolution. However, their benefit should be derived only after the military system has been established.[53] To do otherwise will open the door to a long and complex consensus building process[54] further delaying the deployment of a critical combat capability.[55]

Operational Options

In the development of RASFOR, there are several "optional" areas to consider with potentially large payoffs in terms of operational utility. In actual launch operations, the concept of making the lift vehicle have an abort capability may have merit. The current approach ("lighting the candle") entails 100 percent commitment when the booster is ignited--the system either flies or it dies. An abort-capable vehicle can have built-in subsystems to rescue the payload, and perhaps even the entire vehicle, if sudden loss of the main propulsion system occurs. The decision to pursue this capability should be based on trade-off studies considering complexity, reliability, operational requirements, payload and vehicle availability, and cost.

The implementation of RASFOR can introduce a new option for heavy lift--on-orbit assembly. While this option may require the development of robotic orbital transfer and assembly vehicles, it also offers many advantages over the current one-shot method. As discussed in previous paragraphs, the risk of the full system will be distributed over several launches. Also, if a subsystem fails during on-orbit checkout, only that portion will need to be replaced via RASFOR. If the RASFOR has a parallel launch capability, or if its launch turnaround time is sufficiently short, then the entire heavy system can be on line in the same or less time than currently possible.

For the case of heavy systems that may not be able to be broken down into smaller subsystems (such as a space station structural element), RASFOR may be used in conjunction with conventional heavy lift under what may be termed the "90/10 split" method. In this approach, the majority (possibly 90 percent) of the payload is "dumb" weight--structure, fuel, supplies--while the remainder (possibly 10 percent) of the payload is the "smart" weight--electronics, sensors, solar cells. The 90/10 split puts the "dumb" payload on conventional heavy lift and the "smart" payload on rapid-response spacelift, thus providing the capability to rapidly replace any "smart" subsystems failing to check out on orbit.

Benefits

The benefits offered by rapid space force reconstitution systems are numerous: increased capability, operational utility, and flexibility, and decreased vulnerability, risk, and cost.

Increased War Fighting Capability

The primary objective for developing and employing RASFOR system is straightforward--*provide responsive and flexible space support to the war fighter.* This support is a key enabler for space-based systems serving as force multipliers to increase the nation's warfighting capability. RASFOR system can provide an increased satellite sortie generation rate that may be required to replace failed satellites, or to augment existing constellations.

The use of lightsats can provide more capable and less vulnerable satellite systems. Having a distributed constellation of many lightsats versus a few conventional satellites can be compared to a networked system of personal computers versus a larger mainframe. In both cases, the loss of an element in the distributed system will have a much less dramatic effect on overall system performance than a loss in the mainframe environment. Also, problems within the system are easier to diagnose and repair. From an adversary's viewpoint, the distributed system presents a challenging situation--there are more targets of less value, making the overall system less vulnerable to attack. A distributed lightsat system, coupled with an RASFOR system will present the enemy with a modern-day Hydra: for every satellite "head" they cut off from the constellation, the RASFOR system can be used to "grow" its replacement.

Smaller satellites designed with shorter operational lives can also provide more capable support to the warfighter. The director of the NASA Center for Space Microelectronics Technology addresses the advantages of smaller systems:

> Instead of launching every decade, we launch every year or two years, which maximizes the possibility for insertion of new technology. and you minimize your risk by distributing the launch over five launches instead of one.[56]

Figure 2 illustrates the capability advantage possible using shorter-life lightsats. As applied technology continues to advance in the future, satellite capability will parallel these advances. Both short-life (example: 2-year life) and long-life (example: 10-year life) satellites incorporate available technology advances into their next generations of design. However, the short-life systems are able to go through five generations of improvement for every one generation of the long-life system. The final result is that the short-life system will have a capability advantage over the long-life system for eight years of its life.

An operational RASFOR system can provide a more polemic function to warfighters--it can serve as a platform for aerospace control and force application.[57] For example, RASFOR systems can be outfitted with payloads to perform offensive or defensive counterspace missions, or to conduct strategic attack missions. Such applications can make it possible to deploy precision-guided conventional munitions anywhere on the plant's surface within hours.[58]

Finally, and perhaps most importantly, RASFOR can provide the warfighter with *flexibility at the grand strategic level*. The MILSTAR satellite system has been criticized as being a cold-war system without a mission. Indeed, many of its subsystems were designed under the national security strategies reflecting a bi-polar world under nuclear detente.[59] Because of the global changes occurring during its long development period, the US is faced with a system meeting requirements that may no longer be valid. Implementing a military space structure using RASFOR (with short-life satellites) will provide a more responsive system that can adapt more readily to changes in national security strategy.

Improved Development Process

RASFOR elements have several advantages in development and procurement over conventional spacelift and satellite systems. The emphasis on simplicity, standardization, and operational utility for the spacelift system, coupled with reduced subsystems for smaller and shorter-life lightsats can lead to shorter development and procurement cycles. Standardization of system elements can result in increased development program stability and allow for multi-year procurements and incremental funding reducing program costs by as much as 35 percent.[60] In addition to cost savings, this approach also provides increased flexibility for future space systems. Also,

standardized lightsat buses can provide the core for low-cost technology test beds to reduce program technical risks and their system costs.[61]

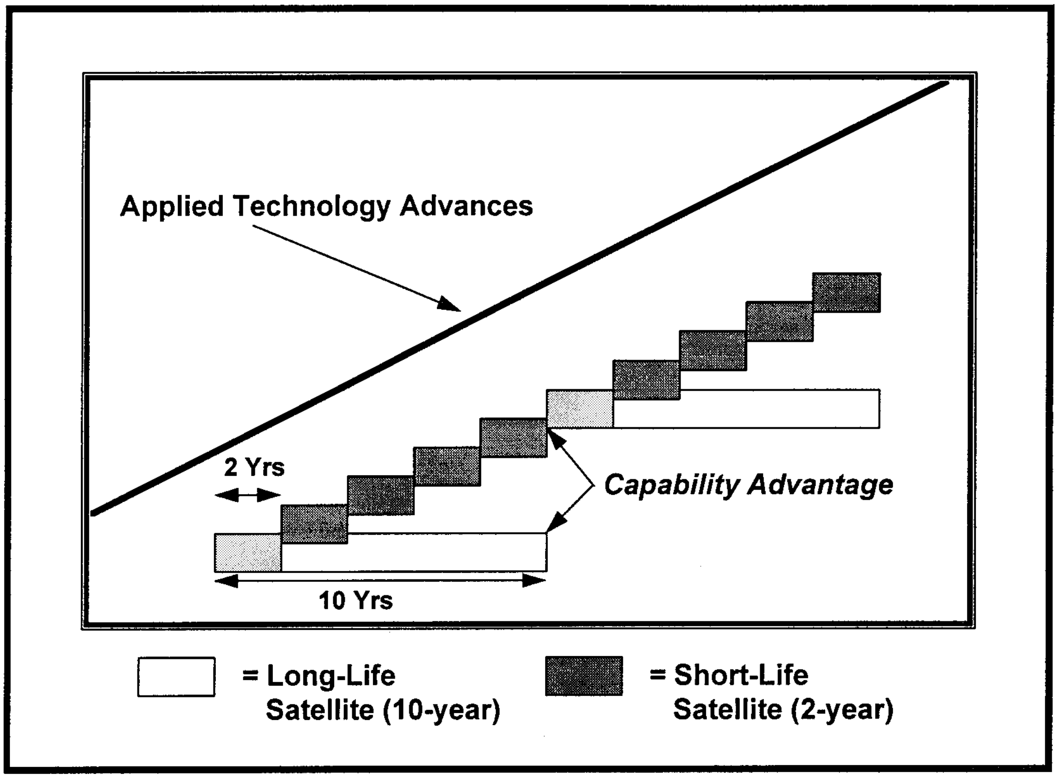

Figure 2. Capability Advantage of Short-Life Satellites

Strengthened US Space Foundation

Although the primary objective of RASFOR systems should be to develop military spacelift capabilities, the implementation of such a program will definitely strengthen the national space-related industrial base. Civil and commercial applications are very likely, including non-space related spinoffs such as medical instruments.[62] However, benefits to the non-military sector are not guaranteed. Industry may have to take some initiative, and even some risks, to benefit from RASFOR systems; the US government must fully support any such initiatives.

The development of turbojet-powered civilian transportation aircraft offers an example that can be applied to the RASFOR system development. The Boeing Aircraft Company developed and produced the B-47 and B-52 strategic bombers for the US Air

Force. These aircraft were designed and built to provide a critical *military capability* - nuclear deterrence. Their design and procurement were not contingent upon commercial aircraft needs, and therefore no consensus building outside of military circles was required. The experience gained by Boeing during the program was applied, at great risk to the company, to the development of the Dash 80.[63] This aircraft was the forerunner of the Boeing 707 commercial transportation aircraft, in essence being the forefather of all Boeing 700-series jets. The development came full circle back to the military when the Air Force decided to use Boeing's aircraft in a version modified for aerial refueling--the KC-135. This success story illustrates that the approach of military first, commercial application second makes sense for RASFOR development.

Conclusions and Recommendations

Doctrine

Space doctrine is still in its infancy. The current version of Air Force space doctrine states that "space forces offer a new operational horizon from which all military forces can benefit by adding to their responsiveness and effectiveness."[64] The irony of this doctrine is that it carries through with its theme with regard to all military forces *except* their own--the issue of increasing the responsiveness of space force support is almost ignored. Most of this doctrine details how to transmit data from space to surface forces and how to deny an enemy's capability to do the same. Little thought is given to how we will react when enemy tries to deny our space forces.[65] The unstated assumption is that US satellites will always be in place when we need them and that existing reconstitution methods (prepositioning, on-orbit spares) are sufficient; no proactive approach to space force reconstitution during combat is presented.[66]

Although the spacelift element of space force reconstitution is mentioned in current doctrine, it is given very low priority. Assured access to space is given lip service in Joint and Air Force doctrine; both acknowledge the problems with current spacelift systems, but do not consider the ramifications of these deficiencies in a combat environment.[67] This lackadaisical treatment of space force reconstitution in current doctrine could lead to disaster in our next space war. This deficiency can be corrected by implementing the following recommendations.

1. **Proactive Reconstitution**. Rapid space force reconstitution (RASFOR) is needed to ensure that these critical assets are always available when and where they are needed. *The essential nature of RASFOR must be emphasized throughout space doctrine.* In a combat environment, the capability to rapidly replace or augment satellites is essential to providing complete and flexible support to joint warfighters. Without this capability, a properly-armed enemy can eliminate our satellites (active and spare) to nullify all force enhancement derived from them. If satellites are not available during wartime, then current space doctrine falls apart. An operational RASFOR system can ensure satellites will always be available when needed--it must be recognized as the key enabler for space doctrine. Therefore, *RASFOR must be added as a tenet of US space doctrine.*[68]

2. **The Space Campaign**. The options provided by a RASFOR system must be clearly understood by campaign planners, especially its ability to react to short-notice crises. *RASFOR must be integrated into space campaign doctrine.*[69]

3. **Requirements**. The scope of operations RASFOR must perform is unknown. Specific requirements must be determined as a basis for RASFOR development, and these requirements must be coherent with future combat scenarios. *As a minimum, the ability of the current US space force to meet two simultaneous major regional conflicts must be evaluated to determine if RASFOR is required.*[70] Other realistic scenarios must be considered, and the best and worst case features of space warfare must be included.

4. **Development and Acquisition**. Once clear operational requirements have been determined for a RASFOR system, its force elements must be developed and acquired. As the service entrusted with aerospace control and exploitation, the Air Force must take the lead in this effort. However, the *participation of all armed services in the requirements definition, development, and acquisition of RASFOR systems is paramount to their success in combat.* The design approaches previously discussed must be emphasized during development, to include the extensive use of prototype or X-vehicles.

5. **Priority.** *RASFOR must be developed with a military-first approach.* RASFOR technologies and systems must be made available to commercial spacelift and satellites (as appropriate for security considerations). However, it must be emphasized that *the system will not pay for itself* and *technological spinoffs, while predicted, are not guaranteed.*

6. **Schedule.** Acquisition of RASFOR systems must support an implementation timeframe of the years 2002-2007. This timeframe coincides with the projected availability of satellites (existing or in production) to fulfill military needs.[71]

7. **Employment.** Based on the advantages offered by RASFOR systems, the US must consider a fundamental space force structure change to lightsat constellations. The actual employment of RASFOR systems *must include a balance of elements dedicated for continuous alert*, and elements dedicated to routine replacement (with the option of moving to alert status during a crisis). For payloads exceeding the lift capabilities of RASFOR systems, the 90/10 weight split method with on-orbit assembly can be used. Finally, RASFOR systems must maintain the operational flexibility to use their spacelift elements as force application platforms.

Future Challenge

"The ultimate objective of military space operations is the effective employment of space capabilities in support of land, sea, and air operations to gain and maintain a combat advantage throughout the operational continuum and across the three levels of war."[72] Accomplishing this objective requires the employment of space forces when and where they are needed--an objective that can be met by rapid space force reconstitution. US space forces are *not* preeminent in their war-fighting capability. Development of a RASFOR system is an *essential* step the US must accomplish to be the number one power in the "high ground" of combat media.

Notes

[1] Christopher D. Lay, "Space Control Predominates as Multipolar Access Grows," *Signal*, June 1990, 78. The ASAT threat is not limited to the destruction of space assets. Lay states there are "many methods that can be used to degrade or disable a spacecraft. Some disabling methods can not be detected until the satellite is put to use."
[2] *Soviet Military Power Prospects for Change 1989* (Washington D.C.: Government Printing Office, 1989), 55-56.
[3] James T. Hackett and Dr. Robin Ranger, "Proliferating Satellites Drive U.S. ASAT Need," *Signal*, May 1990, 155.
[4] Ibid., 155.
[5] Global Reach Global Power, (Washington D.C.: Department of the Air Force, December 1992), 8.
[6] General John L. Piotrowski, "The Right Space Tools," *Military Forum* 5, no. 5 (March 1989): 46. Italics were added to quote.
[7] Piotrowski, 44.

[8] Lt Col Stephen J. Dunning, USAF, *U.S. Military Space Strategy* (Newport, R.I.: The United States Naval War College, 14 May 1990), 9.
[9] Gen John L. Piotrowski, USAF, address to the Michigan State Air Force Association Convention, East Lansing, Mich., 28 July 1989.
[10] John D. Morrocco, "US Uses Gulf War to Frame New Strategy," *Aviation Week and Space technology,* 23 August 1993, 40. The author notes that Operation DESERT STORM was conducted within a timeframe in which "coalition forces were allowed to build up their forces unmolested, a luxury the US cannot rely upon in the future."
[11] Lt Gen Thomas S. Moorman, Jr., USAF, "Space: A New Strategic Frontier," in *The Future of Air Power in the Aftermath of the Gulf War,* ed. Richard H. Schultz, Jr. and Robert L. Pfaltzgraff, Jr. (Maxwell AFB, Ala.: Air University Press, 1992), 242. Gen Moorman noted that, although this event illustrated the flexibility of some of our military satellites, "this feat nevertheless highlighted our need to be able to more rapidly augment our on-orbit capabilities."
[12] David E. Thaler, *Strategies-to-Tasks: A Framework for Linking Means and Ends*, Rand Report DRR-243-AF (Santa Monica, Calif.: Rand Corporation, 1993), 11. Figure 4 is based on a generic operational concept framework presented in this report.
[13] Department of Defense, National Aeronautics and Space Administration, and Department of Energy, *Ten-Year Space Launch Technology Plan* (Washington, D.C., November 1992), ES-1. The current Atlas II SLV is based on the Atlas ICBM; the current Titan IV SLV is based on the Titan ICBM; and the current Delta II is based on the Thor ICBM.
[14] Lt Col Randall G. Joslin, *Spacelift -- A National Challenge for USSPACECOM,* Air War College Associate Programs Research Report (Peterson Air Force Base, CO: 21 June 1993), 8.
[15] Ibid., 8.
[16] TSgt Phil Rhodes, "Stealth: What is it, Really?" *Airman* 35, no.9 (September 1991), 23. Systems developed in each stealth technology generation include: generation 1 -- the SR-71 (Blackbird) and B-1B (Lancer); generation 2 -- F-117A (Stealth Fighter); generation 3 - the AGM-129A (Advanced Cruise Missile); general 4 - B-2 (Spirit); general 5 - F-22 (next generation air superiority fighter).
[17] Moorman, 245.
[18] Joslin, 12.
[19] Maj Robert H. Chisholm, *On Space Warfare: Military Strategy for Space Operations*, Airpower Research Institute Research Report No. AU-ARI-84-3 (Maxwell Air Force Base, Ala.: Air University Press, June 1984), 21-22.
[20] Maj Gen Robert R. Rankine, Jr., "The US Military is not Lost in Space," in *Building a Consensus Toward Space: Proceedings of the Air War College 1988 Space Issues Symposium* (Maxwell Air Force Base, Ala.: Air University Press, April 1990, 48.
[21] Philip Kunsberg, "Space Infrastructure," in *Building a Consensus Toward Space: Proceedings of the Air War College 1988 Space Issues Symposium* (Maxwell Air Force Base, Ala.: Air University Press, April 1990), 69.
[22] Air Force Manual 1-1, *Basic Aerospace Doctrine of the United States Air Force,* (Department of the Air Force, Washington D.C., March 1992), 14. This quote is found in paragraph 3-6.c., which discusses the force enhancement role of aerospace forces.
[23] *Blue Ribbon Review of the Air Force in Space in the 21st Century,* (Washington D.C.: Department of the Air Force, 1992), 9-11, 15.
[24] Roger D. Launius, "Toward an Understanding of the Space Shuttle: A Historiographical Essay," *Air Power History,* Winter 1992, 6.
[25] Launius, 7.
[26] Ibid., 6.
[27] Ibid., 17.
[28] Ibid., 8.
[29] Rankine, 54.
[30] *The Future of the U.S. Space Launch Capability, A Task Group Report,* (Vice President's Space Policy Advisory Board, E.C. Aldridge, Jr., Chairman, Washington, D.C., November 1992), 21.

[31] Editorial, "Ignore DoD on Launch Strategy," *Space News,* 4-10 October 1993, 14.
[32] Rankine, 47-48, 53-54.
[33] Department of Defense, *Report of the Defense Science Board 1989 Summer Study on National Space Launch Strategy* (Washington, D.C.: Office of the Under Secretary of Defense for Acquisition, March 1990), 29.
[34] Joslin, 8.
[35] Lt Col James D. Martens, *Building Blocks in Space,* Airpower Research Institute Research Report No. AU-ARI-89-6 (Maxwell Air Force Base, Ala.: Air University Press, April 1990), 10.
[36] Kunsberg, 66.
[37] *Report on the Department of Defense Space Investment Strategy*, 24 January 1994 Service Coordination Draft, 1.
[38] Ibid., 21.
[39] Quoted in *Economics*, Fifth Ed, by Richard G. Lipsey and Peter O. Steiner (New York: Harper & Row, 1978), 156.
[40] Richard G. Lipsey and Peter O. Steiner, *Economics*, Fifth Ed (New York: Harper & Row, 1978), 156.
[41] DoD Space Investment Strategy, 38.
[42] Chisholm, 22.
[43] Three well-publicized candidates for rapid-response spacelift are the Pegasus, Taurus, and Delta Clipper space launch vehicles. The Orbital Sciences Corporation (OSC) Pegasus is a proven vehicle (first launched 5 April 1990) that can be air-launched from a modified Boeing B-52 or Lockheed L-1011 ("Pegasus Ready to Air-Launch from Stargazer," *Chemical Propulsion Information Agency Bulletin* 20, no. 1 (January 1994): 1, 6.) The OSC Taurus vehicle is a ground-launched derivative of the Pegasus; its first launch was from Vandenberg Air Force Base on 13 March 1994 ("US Defence Department Launched First Taurus Rocket," Reuters Information Services, Inc., 13 March 1993.) Technical details of these vehicles are summarized in: Steven J. Isakowitz, *International Reference Guide to Space Launch Systems* (Washington, D.C.: American Institute of Aeronautics and Astronautics, 1991), 217-230. The McDonnell Douglas DC-X (Delta Clipper) launch vehicle is a test vehicle for single-stage-to-orbit flight. Although the DC-X has not flown into space, it has flown successful hover tests (Michael A. Dornheim, "DC-X Makes Second Flight," *Aviation Week and Space Technology*, 20 September 1993, 39).
[44] *The Case for Space*, White Paper by HQ USSPACECOM/J5V, Peterson Air Force Base, CO, 9 August 1993, 2.
[45] Kunsberg, 62.
[46] Although previously thought to be crude, the spacelift systems of the FSU have proven to be very sophisticated. The reference to duct tape is not meant to demean their technology, but rather it is to serve as a tribute to the operational utility of their fault-tolerant systems.
[47] De-evolution is *not* the same word as devolution; according to Webster's, devolution is "a passing down through successive stages," implying a deterioration or degradation. De-evolution is a term intended to show the reversal or retracing of an existing evolutionary path. For this paper, it primarily refers to de-evolving the development current space launch vehicle to eliminate systems, infrastructure, and procedures that have compromised operational utility. This de-evolution will actually lead to enhanced, instead of degraded, vehicles.
[48] Bill Gunston, *Attack Aircraft of the West* (London, England: Ian Allen Ltd, 1974), 173-175. Mr Gunston presents a concise and interesting case study of the F-111 aircraft development. One of the requirements that should have been addressed was that of speed at low altitudes: "If TAC had not insisted on a low-level Mach number of 1.2, but instead chosen M 0.95 (which would have in no way harmed the ability of the aircraft to penetrate), millions of dollars would have been saved and the requirement would have been meet with ease."
[49] Bruce A. Smith, "Explosion Halts Titan 4 Launches," *Aviation Week and Space Technology*, 9 August 1993, 22. On 2 August 1993, a Titan 4 launch from Vandenberg AFB exploded at 101 seconds into its flight. The cost of the failure is estimated to be between one and two billion dollars. The effects of this incident go beyond just the economics; it "put Titan 4 launches on hold and threatens further delays in the deployment of key national security spacecraft."

[50] Martens, 10. This report provides an excellent commentary on the challenges of developing standardized space systems.
[51] Frank Morring, Jr., "Microtechnology has Uses Beyond Aerospace" *Aviation Week and Space Technology,* 21 February 1994, 87.
[52] Lt Col Larry D. James, *Dual Use Alternatives for DOD Space Systems,* Air War College Research Report (Maxwell Air Force Base, Ala.: Air University, April 1993), 17.
[53] DoD Space Investment Strategy, 39. This report notes that "In some cases, however, space technologies and applications are specialized for national defense, and there is no customer for them except the DoD."
[54] Jeffrey M. Lenorovitz, "White House Spurs Launcher Initiative," *Aviation Week & Space Technology,* 3 January 1994, 20. In this article, Richard DalBello (assistant director of the Office of Science and Technology Policy for the Clinton administration) sums up the biggest problem with current civil/commercial/military spacelift consensus building: "The hardest part of getting what you want is knowing what you want."
[55] An example of spacelift consensus building gone awry: The pursuit of a "next generation" spacelift system has been so mired in politics that it has done little more than change names from "Advanced Launch Development Program" to "Advanced Launch System" to "National Launch System" to its most recent incarnation --"Spacelifter" (this constant change has prompted some to ironically refer to the program as "Shapeshifter").
[56] Morring, 87.
[57] Air Force Manual 1-1, *Basic Aerospace Doctrine of the United States Air Force* (Department of the Air Force, Washington D.C., March 1992), 6-7.
[58] Lowell Wood, "The US Air Force in 2020," lecture to Air University Spacecast 2020 Team, Air War College, Maxwell AFB, Ala., 27 October 1993.
[59] Jim Abrams, "MILSTAR," The Associated Press, 16 March 1994.
[60] DOD Space Investment Strategy, 42-43.
[61] Ibid., 45.
[62] Morring, 87.
[63] R.G. Thompson, "Dash 80," *Smithsonian Air & Space,* April/May 1987, 62-64.
[64] Air Force Doctrine Directive 4, *Air Force Operational Doctrine: Space Operations*, DRAFT, (Department of the Air Force, Washington D.C., November 1993), 1.
[65] Ibid., 16. Figure 4-2 outlines defensive counter space options which includes an option to "reconstitute assets." However, this is one among many options; no further detail is given to this concept except the two words found in the figure. Also, the most of the other options are passive measures that are dependent on existing assets in orbit. If these assets are taken away, so are the options.
[66] Ibid., 23. The section "Crisis and Wartime Space Support" (paragraph 5.1.2.2) does not mention any form of reconstitution.
[67] Ibid., 12, 16. Reference to spacelift is hidden under a subsection titled "Other Considerations" (paragraph 4.3.4.1,) and it is not mentioned under the space role definition of "force support" (3.1.4.). The joint doctrine reference is found in Paragraph 5.a.(3) of Joint Pub 3-14, *Joint Doctrine, Tactics, Techniques, and Procedures (TTP) for Space Operations,* Final Draft, (Joint Chiefs of Staff, Washington, D.C., 15 April 1992), IV-40.
[68] The proper place to add RASFOR to current space doctrine is as a major heading under chapter 4 (Tenets of Space Doctrine) of Air Force Doctrine Directive 4.
[69] The proper place to integrate RASFOR into space campaign doctrine is under paragraph 5.1.2.2, Crisis and Wartime Space Support, in chapter 5 of Air Force Doctrine Directive 4; and under paragraph 5, Space Operations Mission Support, in chapter 3 of Joint Pub 3-14.
[70] In telephone conversations with officials at the Space Warfare Center, the National Test Facility, and the US Space Command J33Z (space exercise branch), the author determined that none of these organizations have conducted studies or exercises to determine if current US space forces could properly support the two simultaneous regional conflict scenario used as a basis for the 1993 Bottom Up Review.
[71] DOD Space Investment Strategy, 24 January 1994 Service Coordination Draft, 2.
[72] Joint Pub 3-14, III-3.

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SPACE MODULAR SYSTEMS

Overview

Currently US space systems are not operationally responsive to the warfighter nor cost effective to the nation. US space systems are custom-assembled on the launch pad where they sit, sometimes for months, waiting for launch day. John T. Correll, Editor in Chief, *Air Force Magazine*, points out in his article, "Fogbound in Space", that only four percent of space shots launch on time.[1] This will not meet the future warfighting commander in chiefs' (CINC) needs. Today's large payloads drive the heavy lift requirements. Those heavy lift requirements are both costly and require long lead times. Reducing the typical payload weight is key towards reducing the need for heavy lift and increasing the operational response times for the combatant CINCs.

This paper advocates the use of small, lightweight modular satellites placed into orbit by light lift, then mated to a permanent support infrastructure in orbit--called the motherboard. One motherboard can be placed into orbit using one heavy lift mission. The motherboard will provide all support services currently aboard every independent satellite, such as power, communications, and fuel. With this capability resident on the motherboard, satellites will no longer need heavy, expensive support, or redundant systems. Modules can perform all the functions carried out by today's independent, expensive satellites. As a result, mission capabilities will increase, while lift response times shorten and operating costs decrease. The SPACECAST team believes the modular concept is the best, most logical, and efficient solution to provide for the increasing needs of the CINC. Consequently, there are several key aspects of the modular concept important to understand:

- The military has pointed out a critical need for space systems to be operationally responsive to the warfighter. This means cutting the delay time between mission approval and actual launch. Today's time frame is unacceptable.

- By breaking the paradigm of large, independent, heavy, and expensive satellites, the US can fully support its military and civilian needs from space more efficiently by taking advantage of the economies of scale offered by standard interfaces coupled with the motherboard.

- Thinking, attitude and imagination are key to changing the paradigm. Just as global power does not require concentration of all aerospace assets on one base, a space system's function need not be provided by enclosing all its capabilities within one skin.

- This concept proposes a modular approach and common satellite interface system to support payloads, thereby requiring smaller and less complex lift.

- The motherboard will be capable of supplying its own energy means and transferring additional energy to packages when needed.

- Given the four organic capabilities of energy, fuel, communications, and self-defense, the motherboard can fully support and defend a myriad of modules and missions sent to it.

- A goal of the modular satellite is to be able to plug-in any type of module into any standard port on any motherboard. This concept can best be exemplified by the way nearly any electrical appliance is able to plug into any standard 110v wall outlet and receive the power it needs to operate.

- Modules will have the ability to:
  -- operate while docked to the motherboard,
  -- operate independently from the motherboard for weeks at a time, and
  -- operate independently by mating with a services support pack provided by the motherboard.

- The ultimate goal of the modular approach is to have distributed systems that are electronically, not physically, connected and cross-linked.

This concept is evolutionary, not revolutionary. It demands a change in philosophy as to how we deploy and support space assets as opposed to a mere change in technology. The modular satellite proposal will employ small modules--each having unique capabilities (such as communications, imagery, energy transfer, etc.) able to support our combat forces. The intent initially is to position a motherboard in orbit that will provide all necessary support functions to the modules (such as power, communications, housekeeping, etc.) through a standard interface system. The modules will contain only equipment necessary for their specific mission (communications, navigation, imagery, weapons, etc.). The motherboard frame will be assembled in space, using a common configuration designed to accommodate multiple support functions. This will allow for maximum flexibility in designing different configurations of modules.

The concept of the motherboard represents a new means to operate in space. During times of crises, the National Command Authority (NCA) and the combatant CINCs will have the flexibility and short-to-immediate response capabilities to crises, which are currently unavailable. To implement the modular satellite concept, there will have to be a change in the way we think of satellites and the exploitation of space. Speed and cost must be the drivers. The best systems do not have to be the most expensive ones. The modular concept allows us to place in space only what is needed to accomplish the specific mission, yet build them to design standards for interface with the motherboard. Modular satellites will provide a building block approach to the most complex of systems. A shift in thinking of space exploitation as an expensive adventure of enormous cost, in terms of time and money, is essential. As the Secretary of the Air Force, Sheila E. Widnall, said, "Customers can't afford every launch to be a unique engineering event. What they do want are dependability, availability on demand, and high reliability at a competitive price."[2] Once this culture shift occurs, the modular satellite concept will become the attractive choice for future satellite operations.

The Capability and Its Relevance

The military has pointed out a critical need for space systems to be operationally responsive to the warfighter. This means cutting the delay time between mission approval and actual launch. Today's time frame is unacceptable (table 1).

Launch Vehicle	*Time to Launch*
Pegasus	*2 days*
Taurus	*5 days*
Delta 7925	*23 days*
Atlas II	*55 days*
Titan IV	*100 days*
Shuttle	*150 days*

Table 1. Launch Delays[3]

Heavy Lift Requirements

Motherboards will be positioned in the common user orbits (i.e., low earth orbit [LEO]--100-500 nm, medium earth orbit [MEO]--11,500 nm, and geosynchronous earth orbits [GEO]--22,500 nm) to maximize operational responsiveness and flexibility (figure 1). Each motherboard structure can be placed in orbit with current heavy lift systems such as the Space Shuttle or Titan IV. Further advances in modular technologies may eliminate the need for heavy lift to place motherboards in orbit.

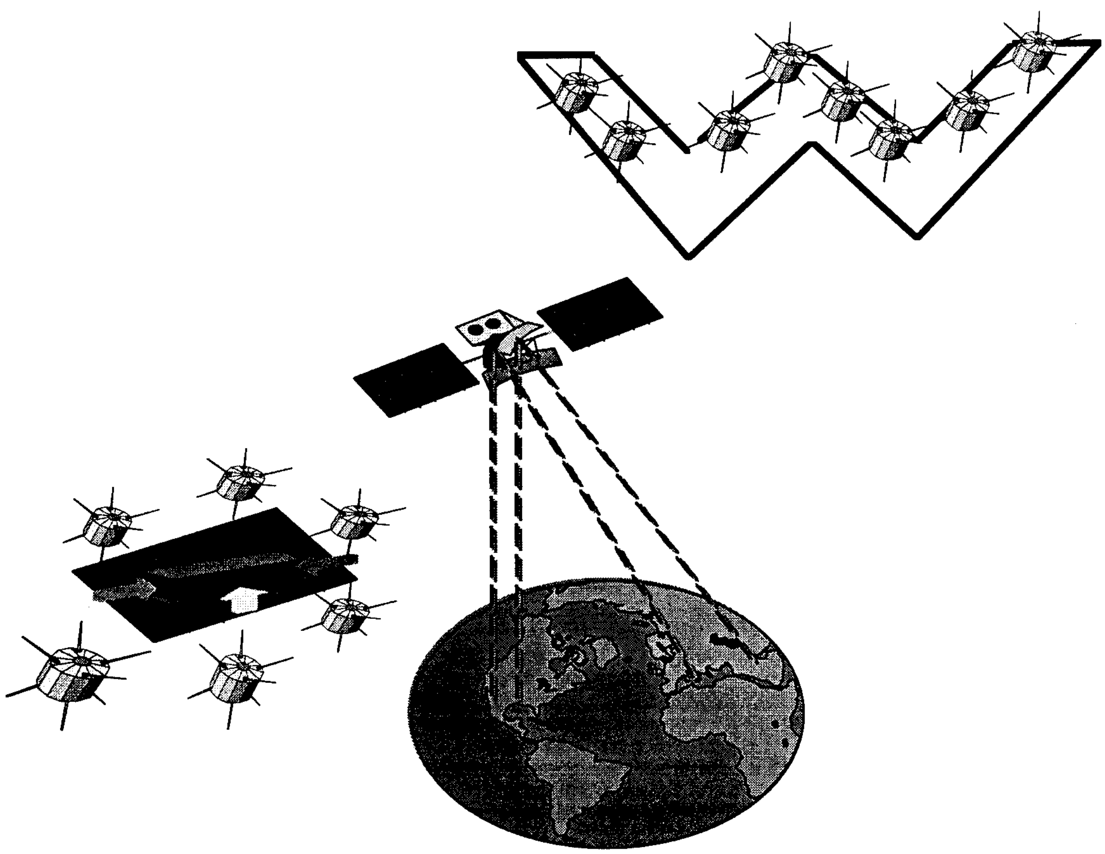

Figure 1. Motherboard Orbits

The Space Shuttle can lift 55,100 pounds (65,000 pounds in 1999 with use of new boosters) to a standard 110 nm LEO. The Shuttle's payload bay is approximately 60 feet long, 22 feet wide, and 13 feet deep. The motherboard will be designed to collapse and fit into the Space Shuttle and will require a single launch to place the entire structure into LEO. On the other hand, the Titan IV, the newest and largest unmanned US space

booster, can be used to lift the motherboard beyond LEO. The Titan IV can carry payloads equal in size and weight of the Shuttle. Depending upon the design of the motherboard, the Titan IV nose payload faring could be modified and the use of current options in nose fairings could be applied.[4] As the modular technology advances in the future some of the smaller launch systems could be used for modular lift.

Light Lift Requirements

By employing the modular satellite concept, lift platforms can be reduced in size, weight, and bulk. Flexibility and responsiveness will be the resulting hallmark. Moreover, if packaged properly, multiple modules can be launched on a single booster. To reduce cost and lead time for development of new lift programs, some current systems and ideas can be used. Some may require modifications and enhancements, but the idea of using light lift boosters makes fiscal sense with today's limited budgets. Just as important are the time savings obtained by not reinventing the wheel by developing new expendable boosters.

Pegasus is a three-stage, solid-propellant, all-composite-winged rocket. It provides a cost-effective, reliable, and flexible way of placing small payloads into sub-orbital and orbital trajectories. Because of the launch parameters and location, this system has fewer down range safety considerations than conventional US systems. It can be launched over the ocean. Many factors add to the performance of the Pegasus. First, the potential and kinetic energy are contributed by the carrier aircraft (NB-52/L-1011). The second factor is the reduced drag to lower air density at higher altitudes where Pegasus is launched. Third, are the higher nozzle expansion ratios at higher altitude for improved propulsion efficiency along with the reduced gravity losses due to the unique flat trajectory and wing-generated lift.[5]

Orbex is compatible with Pegasus payloads. It can carry 425 lbs to 400 nm polar orbit and 885 lbs to 200 nm equatorial orbit. Orbex has vertical payload integration and horizontal vehicle assembly. It employs a dual purpose launcher and transporter combination allowing for check out of the vehicle in the horizontal position and launch in the vertical position. The launcher, designed and built for the Scout Program, has a rotatable base permitting control of azimuth to 140 degrees and an elevating pitch control to the 90 degree vertical position.[6]

The Multi-Service Launch System (MSLS), derived from the now retired Minuteman II ICBM, provides the capability to place up to 1300 pound payloads into orbits to 400 nm. By using standard aircraft flight control systems, a modular approach to vehicle design, horizontal processing, and a PC-based launch control system, MSLS provides a rapid launch capability at low cost. A similar derivative of the Peacekeeper could place several thousand pounds into LEO and a 500 pound satellite into a MEO.[7]

There are other potential options for launching modular systems such as the TAV concept, covered in the lift portion of this study and the single stage to orbit (SSTO/Delta Clipper), or two-stage to orbit (TSTO) lift systems. Also, heavy systems like Titan IV often possess contain unused space within the fairing, offering modular payloads free or extremely cheap lift.

To place modules in orbit, light lift vehicles like Pegasus, Taurus, Minuteman or Orbex could be used. Their payloads of 400 to 1000 pounds will require the packages to be designed to this requirement. With the modular concept, different modules on the motherboard could function as a distributed system and provide the same service that much larger, heavier satellites do today. By using light lift vehicles for the modules, launch points will not be limited to one or two locations. The Pegasus concept of lift is a good example. Small (600 pound) payloads are launched on a Pegasus booster from a B-52 to save 35,000 to 40,000 feet of altitude travel and gravity pull. The modules launched on these boosters can still be sophisticated in design, yet require far less organic or permanent internal support systems since the motherboard will provide these services throughout most of the system's lifespan. Launch concepts advocated in the Air Force Institute of Technology-led SPACECAST Unconventional Lift Study, have very near-term potential or are on the visible horizon and will benefit this concept's needs.

Design Options For the Motherboard

Various possible designs exist for a motherboard (figure 2). Each offers flexibility and survivability, crucial to the satellite's mission. One configuration could have the motherboard at the center, shaped as a flat plane with the modules arrayed around the edges (the top portion of figure 2). This design allows a large number of modules to be connected to a single motherboard. It provides greatest capacity per board. A second configuration could have the motherboard consist of several long rods connected at their ends similar to joints in human limbs (the bottom portion of figure 2). The modules

would be connected at docking ports that are arranged along the limbs. The docking ports would rotate along the limbs' axis to minimize the chance of obstruction or interference between modules. This configuration gives the satellite a "Tinker Toy"™ appearance while providing a more survivable design than the first configuration. If the satellite is hit by an object, only the portion directly damaged would be affected. Another advantage of these two configurations is the capability of transferring modules between motherboards for added survivability and operational flexibility. Without the modular satellite capability, the cost of placing many large, complex satellites in orbit would be overwhelming. Other variations are limited only by one's imagination. Further advances in technology may result in the ultimate goal: a wireless structure without physical connections, similar to the current cellular phone system, but still able to provide support for various modules. The first step, the unfreezing event, is to begin envisioning how large capabilities can be provided by small, interactive parts.

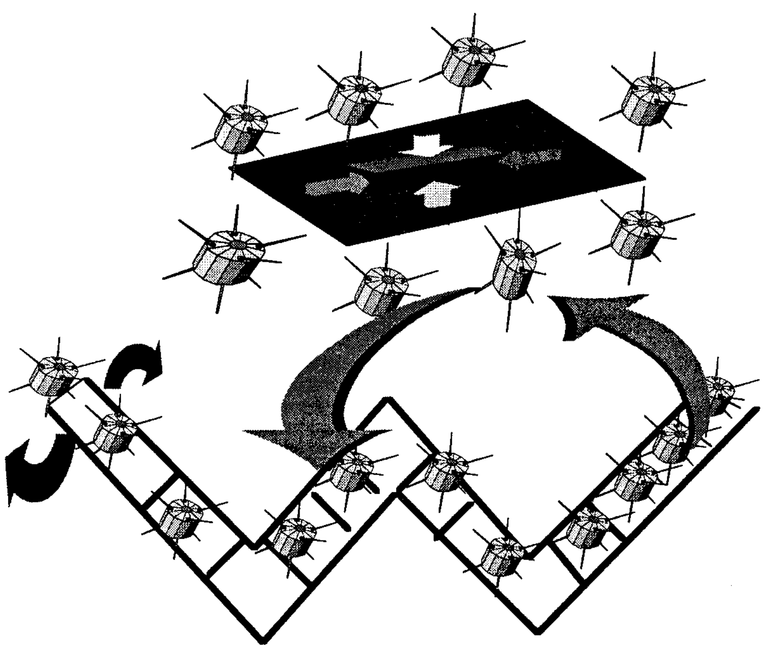

Figure 2. Two Examples of Motherboard Configurations

Future Satellite Interface Standards

Standardized, modular, miniaturized components and virtual reality technologies are providing significant improvements. The flexibility of being able to travel with, and use, electronic equipment worldwide adhering to a common set of standards is coming of age. Logically, similar approaches will be taken for space assets. Standardization will provide the economies of scale necessary for more successful commercial space endeavors. The parallel can be made to the computer industry and the RS-232 interface cable. Modularity will allow the trend in product specialization to further enhance commercial enterprise. The parallel, again made to the computer industry, is the motherboard approach accommodating a variety of chips, allowing you to upgrade to newer chips as they become available. Miniaturization, whether in space or on earth, translates to mobility, flexibility, and the sheer power to do more with less. Commercial space systems using the standardized, modular design concepts can also take advantage of the support capabilities of the modular system.

The modular satellite concept relies heavily on several core ideas essential to understanding its feasibility as a future method of using satellites in space. Among these core ideas are the need to develop and adhere to standardizing packing dimensions, docking, electrical, data, and matter transfer (such as fuel). Consequently, we must take the initiative to implement a set of technologically superior standards to lead the way.

A goal of the modular satellite is to be able to plug-in any type of module into any standard port on any motherboard. This will allow for easy replacement and configuration of modules on any motherboard giving multiple combinations for all satellites. Also, it will greatly simplify repairs, testing, or troubleshooting at any of the docking ports. System problems can be observed and repairs accomplished via a remote telepresence from ground-based space operations centers using remote robotic systems in orbit. Software standards will also have to be designed. This demands evolutionary improvements in space similar to the process evolving with central processing units (CPU) in the personal computer industry (e.g., 286, 386, 486, Pentium, and whatever will follow Pentium).

Satellites not meeting the interface standard can still have their utility extended by designing coupling devices enabling those satellites to dock with a motherboard.

Currently, several efforts are underway to develop small, light satellites in a modular fashion.

Motherboard Organic Capabilities

Each motherboard is designed to operate independently and offer support services for a number of modules. As a minimum, each motherboard must include organic energy, fuel, communications, and defensive capabilities necessary for its own operation and for the modules on board. An energy source is essential for all satellites. The motherboard will be capable of supplying its own energy means and transferring additional energy and fuel to modules when needed. Energy production on the motherboards can include solar, nuclear, thermal, anti-matter, inertial, electric batteries, or any future power source that can be packaged and attached to a standard interface. Fuel to maneuver the motherboard to varying orbital positions will also be required, if maneuvering is desirable.

Refueling individual modules will be one of the primary missions for the motherboard. Bulk fuel may be flown to the motherboard occasionally to replenish fuel supplies. Ideas for fuel storage vary widely to include hydrazine storage tanks, high-density solid fuel packs, and nuclear fuel rods for possible future nuclear engines. Since fuel accounts for much of the weight of a satellite, independent storage tanks could be lifted in bulk to the motherboard. Modules could be launched, nearly empty of fuel, and refuel at the motherboard once in space.

Communicating between the motherboard and ground, air, and space stations, as well as between motherboards and modules, will also be vital for the operation of this concept. Moreover, the motherboard will have the organic capability to facilitate a JTIDS-type (Joint Tactical Information Distribution System) information network for the CINC and the warfighter on the battlefield via its own CPU and communications net (figure 3). Finally, a self-defense capability must be organic to the motherboard.

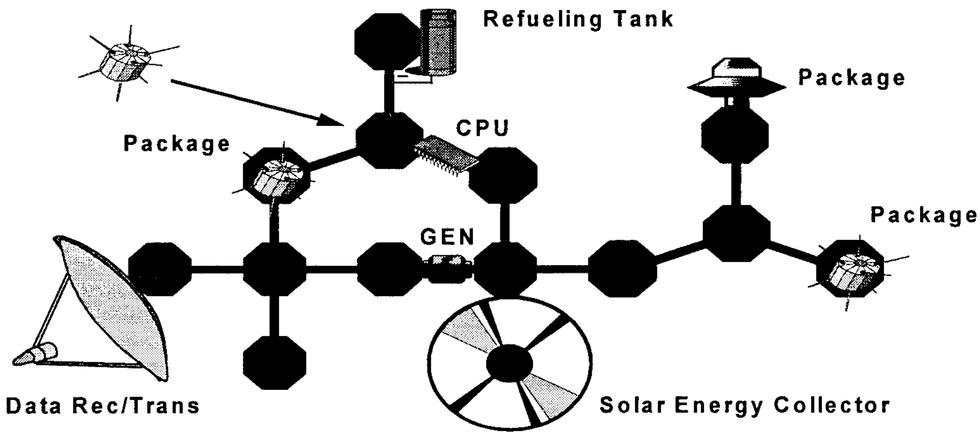

Figure 3. Typical Motherboard Support Capabilities

Although the modules can separate and disperse from the motherboard when threatened, further self-defensive attributes should be incorporated within the motherboard. Stealth technology for the modules and the motherboard would enhance their ability to perform their respective missions almost unseen by adversaries. Anti-satellite weapons will further strengthen its defensive posture. The motherboard can fully support and defend a myriad of modules and missions sent to it.

Modular Satellites

The motherboard concept is achievable with current technologies. Space must become cooperational, requiring a change of the way we think of space. Satellite designs must become more standardized. The miniaturization achieved during the Apollo space program is occurring exponentially across the spectrum of space and electronics research and development. The focus must include the manufacture of relatively small modules capable of interfacing physically and non-physically with space infrastructures and other modules. The modules must be designed to take advantage of low-cost lift options (Pegasus, Orbex, Black Horse) and to maximize flexibility in launch operations (responsiveness). The modules must also realize a high cost-to-benefit ratio. This effort requires adaptation of standard power interfaces[8] and the use of soft docking and computer vision-based guidance and control techniques.[9] Current research for the Space

Station Freedom is addressing miniaturization and other material problems. Solutions will most likely see the same technology spin-offs as previous space programs. Advances in the development of lightweight materials[10] and the resulting miniaturization of major components will prove ideal for applications where weight and volume are essential. Finally, modular fuel and propulsion packs will increase module manipulation.

The modules will be small packages designed for a specific function or mission and mated to the motherboard with a standard interface connection. Standard interfaces will provide the maximum flexibility for module docking to each motherboard. Any module will be able to dock at any position on any motherboard in orbit, provided it can mate up with the standard interface (figure 4).

With the aid of the small lift vehicle, missions from Earth can remove, replace, reprogram, repair, modify, or return modules in much the same manner as we replace light bulbs. Modules can rendezvous with a motherboard in LEO. However, due to the limitations of light launch vehicles, modules requiring higher earth orbits may boost to higher altitudes with orbital transfer vehicles (OTVs) or strap on a booster support pack module from the motherboard. The purpose of the OTV is to provide a low thrust propulsion system capable of moving within an orbital band, as well as between orbital bands. The modules can also be fitted with small dedicated systems (such as power, propulsion, or communications) allowing them to operate independently of the motherboard for short periods of time, such as days or weeks.

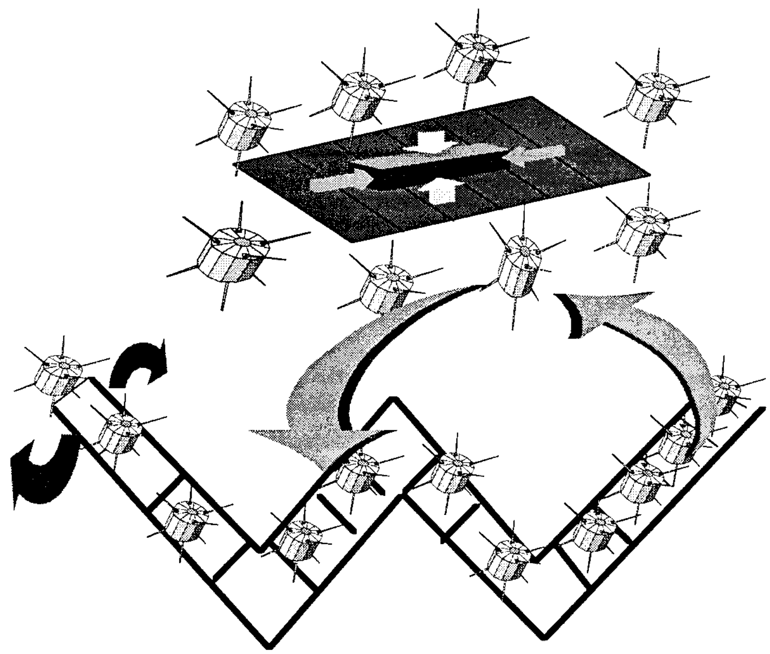

Figure 4. Motherboard Docking

At least three methods for providing operational support to the CINC from the motherboard may be possible. First, modules can separate from the motherboard and enter independent orbits to monitor specific regions (figure 5). Second, modules can be stored on the motherboard. As the CINC's requirements are identified, spare modules on the motherboard can be activated or combined with other modules to provide an enhanced operational capability. For example, modules can combine to increase surveillance capabilities. Additional required modules can be launched on demand with light lift to respond to a particular mission need or threat. Three different types of modular packages give representative examples of applications.

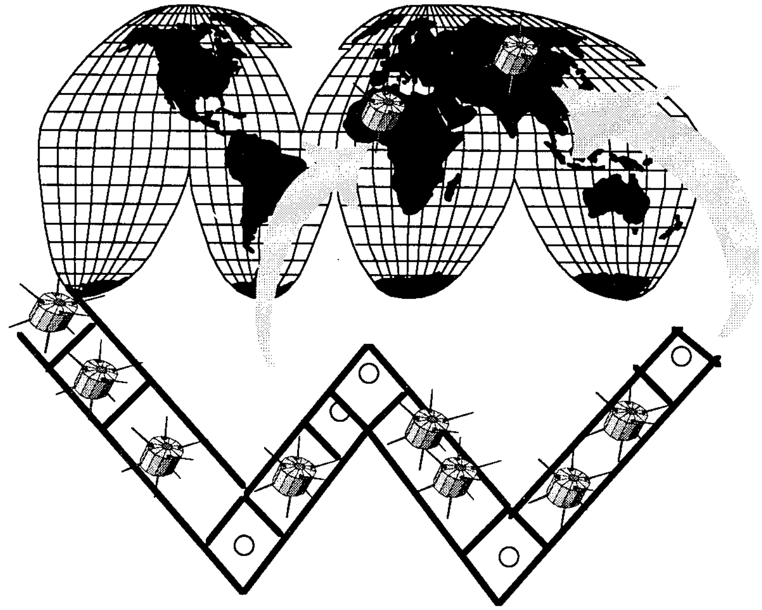

Figure 5. Module Deployment

Emitter Modules

Information is an essential element of the warfighter's ability to win. The need for space-based intelligence coverage is rapidly growing. In this "come as you are" world of globally distributed threats and dangers a global view providing instant coverage of any region is necessary. The CINC's decisions will require the ability to see the area of responsibility (AOR) firsthand. Overhead space assets best provide real-time intelligence information. Fast, accurate intelligence allows the commander to maintain the initiative against the enemy.

Emitter modules might include communications, radar, designators, illuminators, navigation, jammers, IFFs, hologram projectors, weather changers, and debris destroyers. Obviously communications modules are necessary as organic parts of the motherboard. However, additional communications packages may be added to the motherboard to enhance its missions or to lease to the civilian sector. Communications modules can range widely from datalink transmitters to television signal transmitters. Individual

communications links for the soldier on the ground to the commander in the field will be possible via the motherboard packages. These communications links can vary between mere radio transmissions, teleconferencing, or viewing the battlefield in real-time via a module supported by the motherboard. Radar packages can monitor the entire AOR from the motherboard or an independent orbit and relay information to command and control centers instantly.

A goal to pursue is to have the ability to designate or illuminate specified targets from space for smart munitions' guidance--thereby eliminating the need for separate target designating aircraft in large strike packages. Jammers can cover whole regions of the battle area or specific targets, receiving their tremendous power needs from the motherboard. Friendly troops and equipment carrying miniature IFF transmitter/receivers can be instantly recognized by IFF packages and relayed to the motherboard's JTIDS to help avoid friendly-fire casualties. Moreover, hologram projectors can depict units of US forces in different areas of the battlefield to confuse, misdirect, and demoralize the enemy. Systems designed to generate or control weather patterns can also benefit from the motherboard's support facilities. Modules, designed to destroy or decay the orbits of space debris, could use the motherboard's support features as well.

Receiver Modules

Separate modules on the motherboard can also include receivers such as intelligence, weather, surveillance, and arms control monitoring systems. These systems can be further enhanced in the future to present information in a video-type or holographic format to the warfighter or planner. Receivers will include radio, telephone, television, radar, datalink, telemetry, and holographic transmissions emanating from the AOR.

Weapons Modules

The ability to deliver munitions on target has progressed at an exponential rate. While treaties or agreements may prohibit the basing of any space-to-earth strike weapons, should hostilities commence space provides a superior medium for weapon delivery. Warfighters can greatly benefit from weapon systems based in space to provide precise destruction of targets. The first nation capable of force projection from space will change the entire nature of warfare. Projectiles launched from spaced-based platforms

will give the flexibility of total battle space coverage, stealth, and inherent defense. In addition, space-based weapon systems can feasibly locate, assess, and engage targets from a single platform. Weapons modules able to use the motherboard constitute a wide array of ideas and concepts far beyond the scope of this particular section. However, weapons modules can include directed-energy weapons, laser weapons, plasma weapons, kinetic-kill weapons, HARM-type weapons, conventional weapons, and anti-satellite weapons.

Potential Technologies

Virtual Reality

Virtual reality technology needs substantial development before incorporating it into this concept to perform maintenance, refueling, and manufacturing. A near real-time feedback capability from a great distance is required. Research breakthroughs in virtual reality technology require substantial advances before they can be incorporated into this design. In addition, complex operations are required to perform the various housekeeping tasks. A substantial improvement in robotics will also be required to support this concept.

Robotics

Complex manipulations are required to perform the various maintenance tasks. A substantial improvement in robotics, as well as remote command and control ability, will be required. System problems could be observed and repairs accomplished via a remote telepresence from ground-based space operations centers, utilizing remote robotic systems in orbit.

Docking Mechanism and Vibration Control

Efficient docking mechanisms and procedures are necessary. The abstract on advanced docking indicates this technology is very possible.[11] Another major concern for the modular satellite concept is the vibration and transmission disturbances to other operating modules on the motherboard during docking and positioning of neighboring modules. Technology advancements in techniques, materials, and component isolation

will be required to reduce these self-induced vibrations. This will undoubtedly drive research to determine which types of modules will be able to work together on the same motherboard. Furthermore, it will lead to configuration management standards for the satellites. Research in soft coupling techniques, laser radar docking, docking mechanics, and sensors will have to be standardized. Further development in manufacturing small tolerance fittings and micro-component machines will be necessary.

Orbital Transfer Vehicle

An OTV capable of moving through space, with less than orbital velocity but sufficient to pull objects from one orbit to another, will be required. This vehicle will not need to have a high thrust, merely a high specific impulse (high efficiency). Since the system will already be in orbit, it can operate autonomously over days or weeks (slow but steady acceleration) in a highly efficient manner.

Beyond the Motherboard

Distributed Systems

A value of the motherboard is that it demands a new way of thinking about space system capabilities. By thinking of "capability" as the aggregated outcome of separate, interactive, contributing components, it is possible to envision new ways of combining the components. The motherboard is the first step. Small, interactive, proliferated systems are the next step.

The motherboard requires small component satellites. This requirement suggests miniaturization, common manufacturing standards, mass production, and a reduced requirement for heavy lift. The ultimate goal is to substitute the physical connectivity of the motherboard with electronic connectivity and cross-linking. Electronic connectivity and cross-linking afford at least three advantages.

First, and indirectly, reduced size and weight allow reduced reliance on heavy lift. Reduced heavy lift requirements allow smaller launch vehicles and more frequent launch. Small, reusable systems could reduce the cost of lift and lead to space access that is routine.

Second, proliferated and distributed systems allow more resilient networks. If a single node fails, it can more easily be replaced. Proliferated, distributed nodes force an adversary to attack multiple and widely dispersed aim points. If some nodes are lost, brilliant switching schemes could allow other elements of the proliferated system to assume the lost node's function without interruption. The military advantages are obvious.

Third, proliferated and distributed systems can help avoid the technological obsolescence of the on-orbit force structure. As technological breakthroughs occur, and these cannot be foreseen, they can be added to the network without the need to replace the entire network. The same is true for advancements or improvements that cannot be characterized as breakthroughs. A node with the computational capacity of an "886" laptop, for example, can be augmented by a "986" node. The 886 may be technologically obsolete, but it would remain on orbit to augment or serve as a backup for the newer generation node.

Eventually, some satellites may be as small as today's microchip. Unless we have accepted a new way of thinking about systems and space capabilities, our paradigm will reject the opportunities a microchip-sized satellite could provide. Even so, there are some entities that cannot easily be reduced in size, such as human beings (although in the far future genetic engineering may make even this possible for space operations). The motherboard modular idea becomes the foundation for other space applications such as space industrial parks, depots and bases.

Industrial Park

An orbiting, manned platform or Industrial Park, accessible to friendly commercial/civil endeavors will provide the basic infrastructure to support a variety of activities. An operational facility where space is available for customers will encourage space-based manufacturing, innovation, and development. Such an industrial park will perform a wide variety of benefits. The first is a common infrastructure upon which to build. This includes both a physical infrastructure (self-contained pressurized facility, attachment points, gravity for the workers to simplify certain processes), as well as a facility infrastructure (power, communications, docking facilities, and internal transportation) with costs shared by a number of users. The industrial park could take

advantage of direct access to solar power, the vacuum of space, and a near zero-G environment to provide some unique manufacturing opportunities. By permanently placing the manufacturing process in orbit, the expense, risk and constraints of lift-off, performing a manufacturing cycle and then de-orbiting will be radically reduced. All that will be transported into space after initial set-up of the manufacturing process would be the raw materials. Only the finished product will be returned to Earth.

Ultimately, the use and exploitation of space will require human occupation. However, it will more likely be the commercial sector, motivated by profits available through space manufacturing and exploitation, that will lead the way. An orbiting industrial park, using the motherboard support concept, will provide the basic infrastructure and real estate necessary for commercial enterprises to risk capital. Rather than forcing a user to invest in high-cost, miniaturized, ruggedized support systems designed to operate in a zero-G environment, this industrial park will enable the entrepreneur to focus on the process without concern for the infrastructure support. The military can, of course, benefit from spin-offs such as space for facilities and storage, manufacturing and assembly near space systems, and real estate from which to conduct space operations.

Manufacturing in Space

Space manufacturing has a number of significant benefits that are impossible or extremely expensive to replicate on Earth. First, in-space production allows access to a zero-G or near zero-G environment. Theoretical predictions of superior quality microchips, high purity pharmaceuticals and super alloys not possible on Earth are some of the benefits of space manufacturing. Second, the pure vacuum of space provides an ultra clean, biologically isolated environment for advanced chemical and biological processes (reactions and separation mechanisms). In addition, space offers direct access to cosmic radiation and solar radiation. Although there is not now a significant demand for manufacturing processes using cosmic radiation, unimpeded access to solar radiation and limitless space for collecting the energy will give an orbiting platform almost limitless energy. Such clean renewable energy will be of great value to energy intensive industries such as aluminum manufacturing, fusion development, and high energy physics research. Commercial spin-offs might include prototyping for film prop makers, architects, urban planners, and surgeons (prosthesis), solid-imaging for chemists, physicists, biologists, police artists, terrestrial topographies, pattern molds for

manufacturers, industrial engineers, jewelers, and job shops. Commercial space assets implementing the standardized, modular design concepts can also take advantage of the support operations.

Manufacturing processes require space, facilities, power, process equipment and raw materials. They also require time to set up and optimize, and stabilize. Once established, processes can be operated in a continuous mode, greatly reducing operating costs. In addition, raw materials found in space (iron and nickel from asteroids, the Moon, etc.) can be processed into final product (structural beams, vehicle skin) for in-space application. At a space assembly facility, modular satellites, orbital transfer vehicles and deep space probes can be assembled, tested, repaired, and launched without the shocks and loads associated with current launch environments. Such vehicles will not be limited by the size constraints imposed by launch vehicles.

The machines needed to build the parts in space will vary in size, but may, in some cases be comparable in size to today's large commercial copiers and desktop laser printers. These machines will be part of a manufacturing system combining the applications of CAD (computer-aided design) and CAM (computer-aided manufacture) to fabricate the parts seen on the 3-dimensional CAD screen.[12] Just as word processing text is sent to a printer, by 2020, CAD programs could transmit a 3-D computer image to a fabricator machine where the part is manufactured molecule by molecule from metal, composite, or plastic powder. Similar to an ink jet printer spraying the text or graphic on paper, a fabricator would build a part by spraying droplets of metal powder together to form the part (or some other material). Additional benefits will be discovered once research and development of space processes commence.

The exponential integration of CAD and CAM may lead to the real-time computer generated manufacturing of parts in space from raw materials including metal, plastic, fiber, and ceramic powders. Current trends in this new technology are called automated fabrication (AutoFab) and desktop manufacturing. AutoFab is the process of generating three-dimensional solid objects by beaming light on multiple layers of photosensitive plastic polymers.[13] Advances in this technology include computer-numerically-controlled (CNC) milling, micro-machining, CAD/CAM; rapid prototyping, laser sintering, and droplet deposition to streamline manufacturing processes. AutoFab is driving manufacturing towards nanotechnology--where objects are constructed one molecule at a time. The leading experts in AutoFab expect this technology to become

mainstream within 20 years. Furthermore, they believe the entire field of man-made and natural materials to be within the domain of additive fabrication, including soft organic tissues and refractory metals.

In short, automated fabrication incorporates the technologies advancing the generation of 3-dimensional solid objects under computer control. The fabrication process takes raw material in some shapeless form, such as blocks, sheets, fibers, powder or a fluid, and turns out solid objects with definite shape. Currently this process operates under three general categories of subtractive, additive, and formative:

- Subtractive--material is removed from a solid block until the desired shape is reached.

- Additive--material is manipulated to build objects one particle or one layer at a time.

- Formative--mechanical force is applied to bend or press a sheet or soft material into a desired shape. Also, the molding of molten or curable liquids into a desired object.

- A hybrid process is also possible by combining two or all three types of these techniques to build an object. Given the potential sources of raw materials in space, additive fabrication offers the best method for use in space. Of the additive processes, droplet disposition presents some intriguing ideas whereby an adhesive liquid is deposited in a controlled pattern to form an object. Ideally, space manufacturing would use the raw materials available in space or recycle space debris.

Space Assembly

In-space manufacturing will augment space assembly. Components or sub-components, both manufactured in space and transported from Earth, will be assembled and checked-out in a space assembly facility. Currently, satellites and other space vehicles are designed and constructed to withstand the rigors and stresses of launch. They include the redundancy and environmental specifications (i.e., class S parts) consistent with the severe environment of a high-G, high-vibration launch. Once the vehicle is deployed, it operates in a near zero-G environment with little, if any, lateral loads or vibration. In-space assembly and check-out will allow a vehicle to be designed

and built for its operating environment, reducing cost and complexity. It can be tested in space, with any problems corrected prior to deployment.

Space Depot

A space depot will provide on-orbit repair facilities for transatmospheric vehicles (TAV), OTVs and satellites. Once again, the costs of lift, de-orbiting, and re-deploying a satellite will be eliminated. This depot will also reprocess captured space junk, either repairing and redeploying it, or scrapping and reprocessing, or recycling it as raw material. Implementation of a space depot will provide enormous leverage for the US space capability. An on-orbit depot will provide forward-based logistical support for space vehicles. A facility performing the functions described above can lower the payload weight of space vehicles, extend their operational life, conduct product research, mine space minerals and ore deposits, and improve space asset availability and survivability.

Operating Base

We have long recognized the benefit of deploying to a forward location when engaging in extended operations in a theater of operation. Warfighting capability has historically required the ability to provide a presence in the theater of operations. Such a presence has traditionally focused on the control of bases from which to operate at minimal expenditure of energy. Alexander the Great defeated the Persians by eliminating naval access to their bases (the Mediterranean ports) while arranging for himself prepositioned supplies and safe bases from which to operate. Recent experience with Operations DESERT SHIELD and DESERT STORM showed that power projection still requires a forward operating location relatively near the battlefield.

As space becomes a theater of operation in its own right, rather than a communications and observation high ground, there will be a need for real estate upon which to build a base of operation. Such real estate will require power, structure and facilities to enable forward pre-positioning of hardware, to reduce the time, energy and costs associated with deployment, and simply be near the front.

As an operating base, manned activities of all sorts can take advantage of a 1-G environment for physiological extension, recreation, and reduced lead-time to respond to in-space and on-Earth contingencies. It can also act as a staging and assembly area for preparations for deep space exploration and travel, either manned or unmanned.

Summary

The ability to observe, move, shoot, and communicate remain the fundamental keys to success on the battlefield. However, the expansion of the battle space over which commanders must move and communicate, as well as the speed and accuracy required to select and engage targets, have changed dramatically over the years. A commander's ability to observe, orient, decide, and act upon situations during war fighting is becoming more and more key to defeating one's enemy. Col John Boyd calls this process the OODA-loop.[14] By building a support structure in space, the US can maintain its technological lead over its adversaries and enhance its ability to get inside their OODA-Loop. The modular concept proposed by the SPACECAST team is the best way to provide for the increasing operational needs of the combatant CINCs. Indeed, during DESERT STORM, the satellites diverted from other strategic surveillance missions to positions over the Arabian peninsula consumed enough fuel to shorten their useful life by as much as two years.[15] Unfortunately, the US is currently unable to refuel those satellites in orbit. Adoption of SPACECAST's modular concept will solve this vexing problem.

Notes

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[2] Honorable Sheila E. Widnall, "Women in Aerospace, New Directions in Space Engineering and Planning," comments to Aerospace Corp, El Segundo CA, 26 Aug 93.
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[6] Briefing, VAdm William E. Ramsey (USN Ret), subject: Introduction to CTA, Inc. Launch Systems. 1 Sep 93.
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[11] Allen Thompson.
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[13] Ibid.
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PROFESSIONAL MILITARY EDUCATION (PME) IN 2020

The effective employment of air and space power has to do not so much with airplanes and missiles and engineering as with thinking and attitude and imagination.[1]

- Gen Merrill A. McPeak

Visionary and innovative thinking is not just reserved for senior leadership; but must be understood and practiced at every level for an organization to continue to thrive.[2]

- Air Force Quality Institute

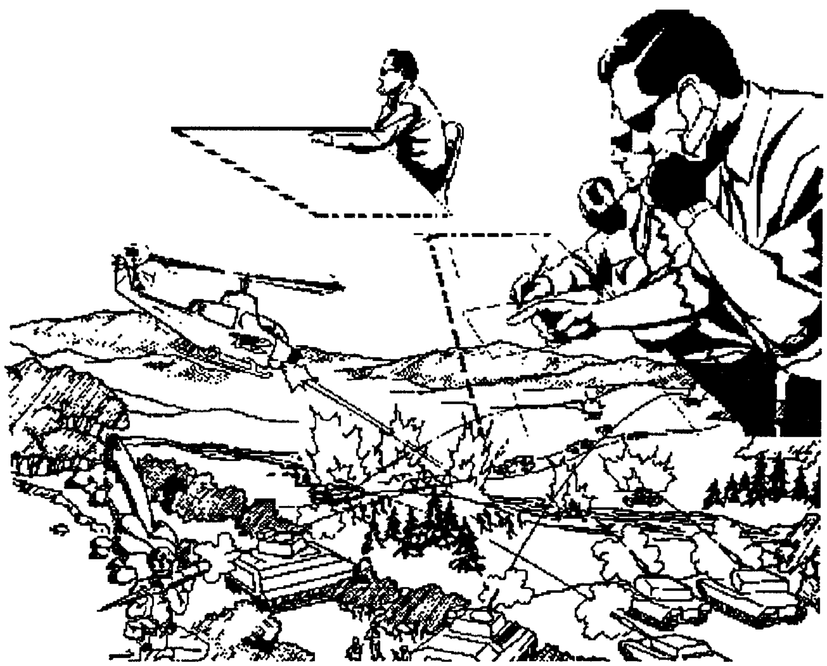

Figure 1. Virtual Lessons

Subject and Problem Statement

As muscle work declines, large numbers of unskilled laborers are increasingly replaced by smaller numbers of highly trained workers and intelligent machines. ... This process, too, is perfectly parallel in the military, where smart weapons require smart soldiers. ... The idea that the Gulf War was a 'high-tech' war in which the human element in combat was

> eliminated is a fantasy. The fact is that the forces sent by the allies to the Gulf were the best educated and technically expert army ever sent into battle. ... The new military needs soldiers who use their brains, can deal with a diversity of people and cultures, who can tolerate ambiguity, take initiative, and ask questions, even to the point of questioning authority. ... The willingness to ask and think may be more prevalent in the US armed forces than in many businesses. ... As in the civilian economy, fewer people with intelligent technology can accomplish more than a lot of people with the brute-force tools of the past.[3]
>
> -- Alvin Toffler

Introduction

PME 2020 will be a residency program, but it will evolve to become a residency program unlike any that exists today. It will encompass all of what currently constitutes military education and training. This program will develop from today's distance learning, multimedia, virtual reality, and telepresence concepts. This paper discusses the evolution of PME. First, the paper describes why the PME system must change. Second, the paper explains how the PME system will change. Third, potential technologies are highlighted. Finally, this paper identifies the emerging technologies and operational exploitation opportunities. Annex A of the paper recommends ten steps that should be undertaken today to ensure the continuation of a successful PME system in the future. Annex B answers the questions of what the future curriculum will include and whether multimedia and virtual reality will fit into PME 2020's curriculum. The "Glossary" contains key terms used throughout this paper.

The virtual resident program of PME 2020 will link highly integrated telecommunications with virtual reality. This future program will ensure the war fighter is able to overcome the challenges posed by the operating environment of the future. These challenges include the informational and technological explosions, smaller armed forces, fiscal constraints, and the technological environment. PME 2020 will overcome these difficulties and will guarantee that war fighters are able to perform their role in national security.

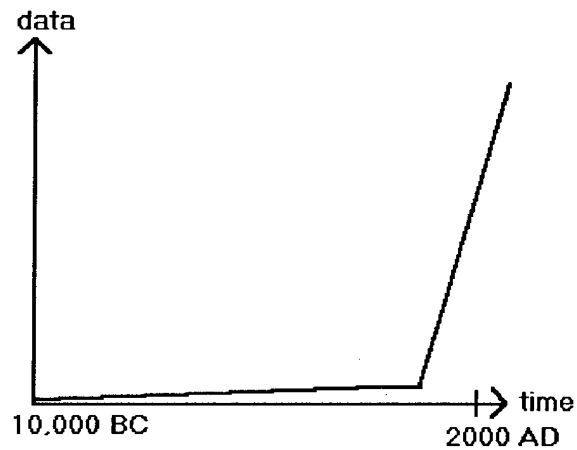

Figure 2. Information Growth

Informational And Technological Explosion

The rate of change in technology and the rate of growth in available information are increasing every day. As the American military increasingly depends on technology and information to both deter and win war, the military member must understand both and use them as the force multipliers upon which the nation has come to depend.

Space, a critical element in any future vision of the US military, provides many examples of the current and coming information explosion. One system of satellites alone, set to launch in 1998 - 2013, will generate more than 10 quadrillion bytes of information about the Earth, "equal to about 10 billion books (Library of Congress holds a mere 27 million)." [4] The "Clementine" mission, now underway, is sending back 10,000 times the imagery of its predecessor.[5] "But sending data-collecting satellites spaceward is only half the task. Storing, analyzing, and rapidly disseminating the information once it is sent back will prove equally difficult."[6] "The helical scan storage technology NASA currently utilizes stores 45 terabytes [equal to 500 million pages of information] on top of a desk."[7] How will future military analysts quickly determine and locate the critical information which can mean life-or-death and success-or-failure in the combat environments of 2020? The military education system can help analysts and operational units by determining which methods and technologies will be needed. PME 2020 must prepare the future war fighter for these informational and technological explosions. Information itself could be the next battlefield.

Figure 3. In the Mind's Eye

Personnel Changes

By the year 2020, the characteristics of military members will be significantly different than they are today. In particular, fiscal constraints will continue to impact the number of military members who will attend or enroll in PME.[8] First, there will be fewer military personnel of all ranks in 2020. Accordingly, the impact and cost (including opportunity cost) of attending in residence will be higher because there will be fewer people to fill in for anyone going TDY or PCS to school. Second, personnel will be at scattered locations in the US and abroad, locations which may be very different from those today. Third, there will be fewer personnel of senior rank, officer and enlisted, at any one location. This means both a higher opportunity cost incurred for those who must leave the unit for education or training and also less chance of finding enough people of a given rank to constitute a face-to-face on-location seminar. PME 2020 must be able to accommodate this smaller, geographically separated military force that may not be able to afford the opportunity to attend lengthy and costly resident PME.

> In addition, the characteristics of 2020 PME students will be different from those enrolled in PME today. In 2020, students will be more familiar and comfortable with technology. For example, they will have grown up with virtual reality in the home and school. Personnel will also be familiar with the blurring between work, education, and home life and with the multiple careers and diverse demands on workers of 2020.[9]/[10]

Figure 4. Declining Budgets

Fiscal Constraints

Military budgets, as a percentage of real GNP, will continue to get smaller in the future.[11] There will be less money spent on travel than now. This infers fewer TDY's and PCS's to attend PME and other specialized training. There will be less money for many kinds of equipment and infrastructure. As the military appropriation tracks downward, costs for technological capability (desktop, especially) are falling between 30 and 68 percent per year (and appear to be able to do so indefinitely). Therefore, fiscal constraints will mean increased use of technology to cover for personnel who are traveling or whose jobs have been automated or eliminated. PME 2020 should be able to better educate more people with fewer dollars.

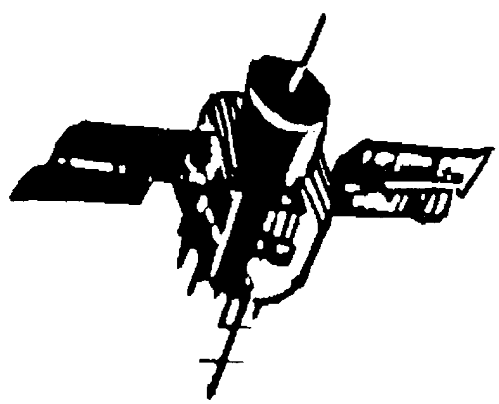

Figure 5. Applied Technology

Technological Environment

The technology environment surrounding military members will be very different than the one today.[12] Even assuming no revolutionary breakthroughs, unlikely though that is, and only maturation of existing technologies (meaning anything currently in use,

planning, or research), the technology environment of 2020 will be a rich one. It will include commonplace use of artificial intelligence, intense miniaturization, expert systems, virtual and artificial realities, and automated "computer assistants." PME 2020 must harness this technology to better educate the entire military force.

In Summary

PME must respond to current and continued changes in the information and technological explosion, military characteristics, fiscal constraints, and changes in the technological environment. Consequently, PME 2020 will have an entirely new look, feel, and responsibility. More importantly, PME must begin changing now to ensure it maintains capability and relevance to positively impact the future war fighters and guarantee their ability to contribute to national security. This paper will focus on the impact of each of these areas while discussing PME's current and future capabilities and relevance to war fighters.

The Capability and Its Relevance

> "If we should have to fight, we should be prepared to do so from the neck up instead of from the neck down."
>
> \- Jimmy Doolittle

Introduction

"Virtual residency" is the linking of telecommunications and computers in PME 2020. While the present PME system may be adequate today, it will not be adequate in the future without significant changes. PME must have new and different capabilities to meet the military challenges in 2020 and beyond. First, PME 2020 must respond to the information and technology explosions by teaching the war fighter how to navigate the information highways. Second, the system must deal with the personnel changes and challenges by, 1) tailoring education to individual needs, 2) contributing to retention of the best-qualified personnel, 3) capitalizing on an enlarged technology comfort zone, 4) being aware of society's falling educational standards, 5) taking advantage of the changing work environment, 6) aiding productivity and innovation, and 7) realizing every military member needs quality PME. Third, PME 2020 must thrive within fiscal constraints by improving results while reducing costs in money and time. Fourth, the system must maximize the technological environment by keeping every military member "connected."

Fifth, PME 2020 needs to broaden its horizons by becoming an open system which educates everyone (including potential adversaries), with a curriculum that is continuously updated and distributed using enhanced distance learning methods, known as virtual residency in PME 2020. Finally, the questions raised by critics about the proposed PME 2020 system will be successfully answered.

Responding To The Information And Technology Explosion

By 2020, information needs will grow exponentially and the amount of new information will be astronomical. Without careful planning and information-handling skills, the decision-makers of the future will be susceptible to "analysis paralysis."[13] Estimates show new information will double every few weeks (or days) due to quantum leaps in technology and the number of people using it. Instant access to the Information Super Highway, the Library of Congress, and numerous other sources worldwide will create an information overload almost unimaginable today. The technologies and techniques associated with the PME 2020 system will aid the war fighter when navigating the information highway.

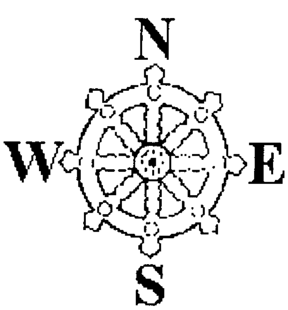

Figure 6. Information Compass

Learning To Navigate

Information navigation (searching) skills, will be critical for all who expect to navigate the rapidly increasing sea of information. PME 2020 problem-solving techniques will emphasize the skills required to narrow the search for critical information in the aircraft, ship, or tank. The PME system will be much more adaptive, enabling it to respond to this ever-increasing and changing world of information. PME 2020 's theme is capsulized in the statement, "knowing the knowledge terrain will be as important for Third Wave armies as knowing the geography and topology of the battlefield was in the past."[14]

Dealing With Personnel Changes And Challenges

PME 2020 will be divided into smaller blocks of instruction which address the specific needs of individuals without regard to rank or position. In addition, PME will be accomplished more quickly and efficiently ensuring the military member keeps pace with the information explosion. PME will respond by building comprehensive lesson systems which will teach a broader range of skills. PME will also expand its individualized educational outlook, by including basic level training in many general areas, while providing specialized training in a more narrow range.[15]

Tailoring Education To Individual Needs

PME 2020 will be an individualized, self-modifying education system responding to the learning modes of each student. It will adjust its courses and the answers it provides to questions as the data changes from day-to-day. Faculty will be able to concentrate on instructing at higher levels of learning and developing courses for entirely new areas of instruction.

PME 2020 will ensure students understand the technology of 2020 by incorporating on-the-job training (OJT) for systems specifically needed to accomplish their mission. PME 2020 will provide the means for transferring this specialized or general OJT directly to the war fighter by "beaming" it into aircraft, tanks, or ships.

Individuals thus trained will have the flexibility to be stationed wherever needed and know the job requirements or be capable of learning them quickly. PME 2020 trained individuals will become a "force multiplier" to the military.

Recruiting And Retention. Keeping The Best Qualified

PME 2020 will directly contribute to recruiting and retention. The virtual reality, computer simulations, and telecommunications technology associated with PME 2020 will attract those interested in state-of-the-art technology.[16]

> As we downsize our military, there is a critical need to prevent any decline in the readiness of our armed forces. As forces and budgets shrink, there is

> the danger that training and maintenance will suffer. The increasing frequency and duration of deployments will eventually make retention of high quality personnel more difficult.[17]
>
> -- Policy Letter from the Secretary of the Air Force

The level of technology represented in PME 2020 and the ability for personnel to be in contact with virtual seminars and research groups and to continue instruction, even while on deployment to remote regions, can aid retention. Research results indicate the environment and opportunities of PME 2020 should be conducive to retaining technologically-oriented individuals.[18] How can the military apply these results to its education system to keep the best of its people? A virtual reality PME 2020 system linked through telecommunications will provide the forum for all interested students to work on high priority, real-time projects. This will help to recruit and retain the best-qualified personnel for the military.

Enlarged Technology Comfort Zone

To meet the future challenges, PME must also take advantage of the changing characteristics of its people. The pre-adult environment of 2020 military recruits will have habituated them to technology and to more readily accept technological changes. The current 20-something generation already considers itself "masters of technology" and "use computers the way other generations use the phone."[19] Succeeding generations will be even more technologically sophisticated. Regarding the shift to interactive simulations for training, Gen Carl E. Mundy, Marine Corps Commandant, stated:

> ...it's very exciting for these young people, sitting down to work in arcades like they have in shopping centers. The Stinger (missile) trainer, for example...It's fun ... It (increased use of simulations) will save us a lot of money in the long run.[20]

PME 2020 will capitalize on the skills the students bring to it. Virtual reality, telecommunications, and computers will be nothing new or threatening to the students and faculty of PME 2020 -- although there will be a transition period to reach that time required to make the adjustments.

Expectations Regarding Knowledge And Learning Skills

In 2020, war fighters raised on the successors to Nintendo and MTV may expect instantaneous answers to their questions, but they may or may not join the military with the necessary skills to use that information. The current college generation is characterized as "victims of declining educational standards ... Three quarters of college professors say students are 'seriously unprepared' in basic skills."[21] This may still be a problem in 2020. PME 2020 must be able to respond to the education and training needs of these individuals. A system that provides access to all resources at all levels to all students is the best method to counter any problems with basic skills. PME 2020 will be just that. A military-wide, virtual residency system both flexible and resilient may be the best means to set, maintain, and enforce standards in education.

The Changing Work Environment

PME 2020 will have to respond to the changing work environment. Increasing numbers of challenges such as new warfare forms, combined with a technical environment which is, in the words of General McPeak, "dynamic to a degree different from anything in human experience," and which when added to our "getting smaller quite quickly," will mean our people will have to be "more comprehensively trained, less specialized," and will have to cycle back through school often during their careers. They will need a "broader range of skills," in order to be "more flexible."[22] Virtual residency will provide the means for military members to accomplish those ends.

Part of the building of the PME 2020 system should include implementing a change in the workday/workweek paradigm to include scheduled sacrosanct times (similar to the "Minuteman Education Program") for individuals to attend PME 2020 courses. Commanders must make the commitment to education and training to ensure time is set aside. PME 2020 must be as easy to schedule and attend as a staff meeting, including coordinating times for "virtual" seminars with members at geographically-separated locations.

Synergistic Effects

The telecommunication aspect of PME 2020 will provide PME connectivity to every military member. This capability will allow individuals to broaden their expertise and become educated in areas outside of their primary career fields . Additionally, the potential exists for unique combinations of backgrounds and interests working within the system on the same project. This interaction will increase productivity and innovation in the military by enabling creative minds to maintain and act in what should be a dynamic educational and training experience.

> ...if you asked a panel of experts in a field when something was going to happen, they were much more conservative than a counter-group of experts from another field outside the topic because the outsiders were less tied up in the immediate problems. They could see the bigger picture ... So, the most interesting things I hear about economics do not come from economists, they come from psychologists, or from geneticists. And the same thing would be true in reverse. The most interesting things economists say have little to do with economics.
>
> I believe that we're moving toward a world of multiple careers, which means that we may eventually branch out after many years in one field. Instead of a lifetime of specialization in a single topic we shift to another. We may lose the benefits of deep specialization, but we will gain the advantage of creative insight and analogy from one field to another.[23]
>
> -- Alvin Toffler

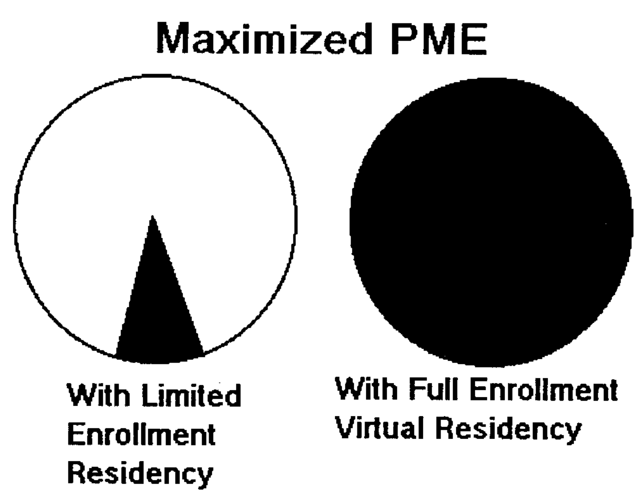

Figure 7. Maximum Opportunity Realized

Who needs PME? Everyone.

> Nearly everyone seems to agree, however, that the strength of today's force lies not only in the strategic acumen of its senior commanders, but also in the demands placed on those leaders by an astute and inquisitive rank and file. "Whether you're talking about a general or a lieutenant, military leaders today are challenged by bright capable soldiers who ask tough questions," says Rep. Skelton. "Gone are the days when a Gen Custer could tell his soldiers to get on their horses and ride without ever having to explain why. Maybe he SHOULD have had to explain."[24]

PME 2020 must constantly educate every military member. As Tom Peters states, in his book *Thriving on Chaos*, we must: 1) invest in human capital as much as in hardware, 2) train entry-level people and then retrain them as necessary, 3) train everyone in problem-solving techniques to contribute to quality improvement, 4) train extensively following promotion to the first managerial job; then train managers every time they advance, and 5) use training as a vehicle for instilling a strategic thrust.[25]

This need to have a better-educated and trained force requires all military personnel receive their education and training through a quality PME system. The PME 2020 system will continue the "seminar" experience through "on-line" seminars and virtual residency. During the transitional years before virtual reality technology matures, virtual seminars will initially meet via video teleconferencing centers at their home units. All groups in the PME 2020 system can share in these on-line seminars. This virtual residency system also provides for contacts across rank lines, between services, and among the civilian world. The virtual residency concept of the PME 2020 system will become the norm.

Living Within Fiscal Restraints

PME 2020's potential accomplishments are limitless however, dollars required to educate and train war fighters are finite. Fiscal constraints must be considered and accommodated. For example, due to fiscal constraints, there will be fewer high-priced weapon systems developed and more frequent, incremental, technological upgrades to existing systems. This will require frequently rethinking uses of the systems and retraining users -- i.e., the war fighters and their support personnel. For this, the virtual reality learning environment is ideal. Even beyond this (or before it), "simulate before you build"

is becoming a military principle -- virtually exploring the problems, benefits, and trade-offs of training people to use the new system, educating leaders in employing the systems, and experimenting with possible counter-measures and limiting factors.[26]

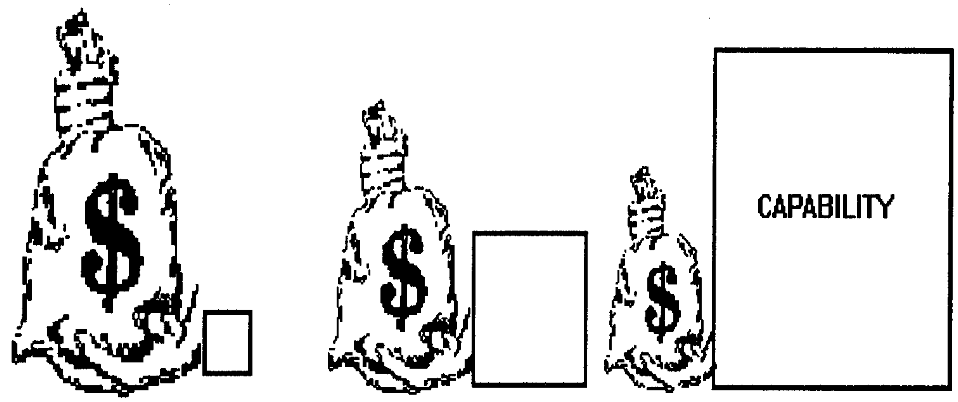

Figure 8. Buying More With Less

Reduced Cost With Better Results

PME 2020's use of interactive technologies for delivery of instruction will reduce costs and improve results. Studies demonstrate as much as 50 percent or more reduction in time needed to learn, compared to conventional delivery.[27] Digital Equipment Corporation reported saving 40 percent of training time by using multimedia instead of traditional classroom teaching. IBM marketing education division reported time savings of 40 percent.[28] Federal Express saved 60 percent of training time.[29]

IBM is a prime example of how the interactive technologies will reduce military costs and provide better results. It reported an overall savings of more than $150 million per year, with much of the savings coming from 300,000 employees not traveling to receive their instruction.[30] The military will see similar dramatic savings by eliminating much, if not all, of the physical residency requirement for courses -- and thus eliminate much of the TDY, moving, dislocation, per diem, and other costs of students attending resident courses lasting from several days to 10 1/2 months. Virtual residency has the potential to train more military members, more effectively, for less.

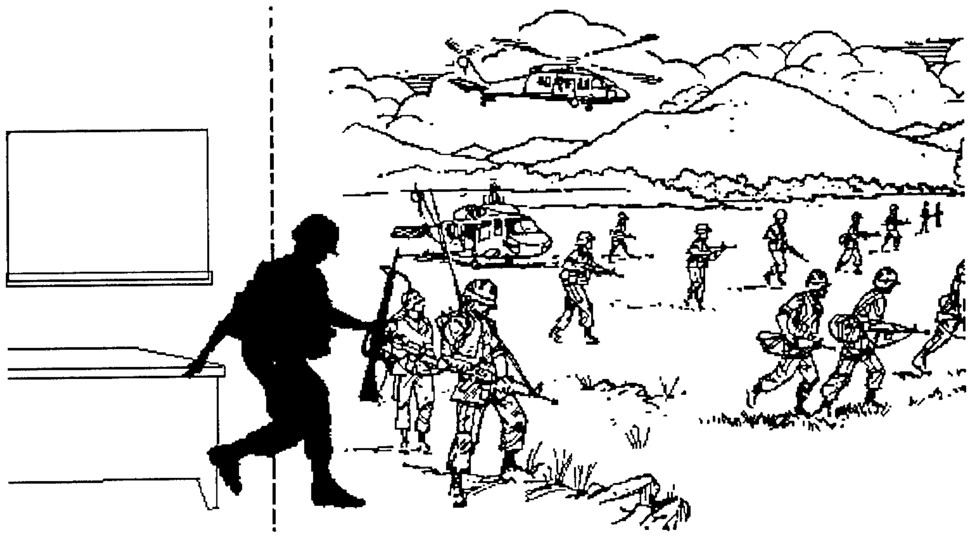

Figure 9. From the Office

Need For Nonresident Education - Virtual Residency

Shrinking budgets will reduce military forces and other DOD resources by 2020. Those reduced forces will still be widely distributed in the CONUS and overseas, but in fewer locations. Consequently, there will be fewer personnel available overall and at fewer locations to participate in PME as students, faculty, and course authors. With fewer human and materiel resources, the value of each will increase. This will place a premium on more effective educational and training programs. For example, by the end of a 20-year career, an Army officer today may have spent more than five years in the classroom.[31] It is doubtful, with the limited personnel of 2020, whether the military will be able to tolerate losing individuals from operational locations for 25 percent of their careers. The costs of sending personnel to resident PME programs (including time lost from their operational jobs) must lead the military to reexamine the benefits of attending resident courses -- and to look for viable alternatives, such as PME 2020. Enhancing the PME system, in spite of fiscal constraints, can be accomplished by converting to a solid, adaptable, virtual resident education and training program. Virtual residency is the most effective and efficient method to maintain high standards of military education, especially with respect to rapid changes in technology and doctrine -- changes with which the military must constantly stay abreast.

Maximizing Effectiveness In The Technology Environment

All 2020 military personnel will be "connected" to data bases through wide area networks such as Internet. By the middle of 1993, Internet alone was already interconnected with over 15,000 other networks and over 20 million primary users.[32] Internet's membership is currently growing more than 20 percent per month.[33] Regardless of unit location, military personnel will have access to worldwide information networks capable of two-way data, image, and simulation transmission. PME 2020 must remain flexible to take advantage of this situation and be brought closer to the individual on a daily basis to ensure education or training requirements are met.

Figure 10. Virtual Classroom 2020

Connectivity Is The key

> 'What telecommunications does is to remarkably expand the quantity and quality of information resources that can be in a classroom,' says Linda Roberts, a senior associate in the Science, Education, and Transportation program at the US Congress's Office of Technology Assessment. 'And by 'information resources,' I'm not just talking about what's written down or what's stored in a digital world -- I'm talking about the ability to work with other classrooms, to expand the community of learners, and to have real access to people who know something, whether that means scientists in research laboratories or people in the business community or politicians who are grappling with decisions.'
>
> ... demands on the 21st-century work force are likely to include not just familiarity with computing, but a capacity for cooperative learning, both of which are fostered by educational networks.[34]

For individuals to take advantage of this new concept of an integrated and flexible job and education combination in 2020, all military personnel will need to be electronically "connected" to the PME system. Furthermore, PME 2020 will be available to all personnel, including those working in remote locations or at sea.

For Faculty as Well

The telecommunications aspect of PME 2020 will also have a positive impact on the faculty. Edward Mabry, a communication researcher at the University of Wisconsin, highlights this concept:

> Historically, the strength of an academic department rested with its resident faculty. Now it depends on the extent to which each faculty member is interconnected with other professionals -- worldwide -- pursuing similar interests. And these associations do not rely on face-to-face contact. We now have electronic research teams and electronic water coolers.[35]

A study by Carnegie Mellon University, analyzing interaction and productivity of scientists in the area of oceanography, also supports this concept:

> Frequent users (of networks) are the more active, productive scientists. Scientists who use the network more also produce more papers, receive more professional recognition from their peers, and know more (other)... oceanographers.[36]

The faculty, as well as the students, of PME 2020 will directly benefit from the technologies incorporated into the system.

Broad Horizons

PME 2020 will be a two-way gathering and sharing between students and faculty while simultaneously building an infrastructure on the expectations and experiences from personnel at all levels. As General McPeak stated:

> Healthy dialogue is important to any organization. ... By the way, a healthy dialogue includes listening to opposing views inside the organization. Openness is a two-way, and often rough and tumble process.[37]

Open System

PME 2020 will be an open education and training program. To efficiently utilize military resources, information will be shared between services and with civilian institutions, especially in research and curriculum development. Military and civilian

educational institutions have much to share that will benefit both. For example, history lessons might be developed by PME academies or civilian institutions and then shared between institutions. Current commercial CD-ROM's already include disks on almost every major war in US history as well as information on the space system and military aircraft. Military schools and other military organizations may find that their methodologies, information, and courseware have commercial value.[38]

Involving And Educating Others

Figure 11. The Class of 2020

The telecommunications and open system aspects of PME 2020 will directly contribute to increased understanding and support for the military. PME 2020 will have the capability to reach larger audiences, such as the media, Congress, the public at large, and potential adversaries. It will educate the press to ensure they understand the military situations they cover, and are able to provide the public with balanced coverage, providing the military with constructive feedback. PME 2020 will educate Congress and other civilian leaders, helping them make fully-informed decisions affecting the military. PME 2020 will also educate the American public. A public, better informed on military capabilities, competence, and needs, will be beneficial for America, improving the chances of continued public support for the military. As Alvin Toffler observed:

> ... smart generals understand all too well that wars can be won on the world's television screens as well as on the battlefield. ... Media policy, therefore, along with policies for communication and education, will together comprise the main distribution components of any overall knowledge strategy. [39]

Educating Potential Adversaries

Finally, the telecommunications and open system aspects of PME 2020 will be available to educate our potential adversaries. Although select foreign officers already attend US military schools, including intermediate and senior service schools, this concept will be greatly expanded with most of PME 2020 open to military officers of all ranks from all nations -- in any location where they can connect with PME 2020. There are many benefits associated with this open concept. The war-prevention and negotiation processes may be easier with "informed" opponents. They may understand and perhaps begin to share our ideals and values. More importantly, they may begin to think and solve problems in ways familiar to us. Information gathered through the PME 2020 system may convince possible opponents of the benefits of non-lethal warfare. In addition, it will convince them that the US military is extremely competent and capable.[40]

Continual Timely Updates Of Curriculum

PME 2020 will be a truly up-to-date curriculum. First, since courses will be available on-demand, military members will be able to learn skills and find information when needed. Second, by establishing expiration dates on courses with time-sensitive material, PME 2020 will ensure currency is maintained and past graduates of those courses are cued to their need for refresher courses or repetition repeating of the original courses. Finally, for all courses, the course material will be continually, electronically updated.

Virtual Residency Is The Key

Virtual residency, with a core curriculum and consolidated resources, is the most important aspect of PME 2020. First, PME 2020 will have a core curriculum integrating land, sea, air, space, non-lethal, and information warfare. Second, the resources of PME 2020 institutions will be consolidated where practical and will be highly integrated electronically. Finally, virtual residency will be the main means of educational distribution. The move toward this process has already begun in the military. For example, the Air Force Institute of Technology (AFIT) began their nationwide distance education course in systems planning and management last year. Serving over 7200 students, it should have a cost benefit of $20 million over 6 years.[41] Also, AFIT has an ongoing Professional Continuing Education program, making use of satellite links throughout the Air Force.

This type of distance learning, in addition to being more cost-efficient, will be more effective in accomplishing joint education and training. More and more, the services are looking at sharing education tasks and resources to achieve those cost benefits, especially with distance education.[42] In 1992, Maj Gen Larry Day, Deputy Chief of Staff, Technical Training, Air Training Command, stated,

> In the next decade, more and more training will occur away from traditional training sites ... The concept [distance education] will save on travel and per diem costs and should be a routine training technique for all the services within a decade... The effort [to share training across services] is led by a little-known group called the Interservice Training Review Organization.[43]

Furthermore, as previously discussed, reductions in faculty and other academic resources will necessitate increased sharing among the remaining military and civilian institutions, which will further advance the case for enhanced distance learning. Virtual residency is a natural and needed extension of current distance learning methods and will ensure the success of PME 2020.

Are There Objections?

In considering objections and resistance to implementing these changes to the PME system, it might be well to keep in mind the words of Alvin Toffler:

> I think the main failure of culture is the failure of imagination. It's very hard to think outside the boxes -- cultural box, institutional box, political box, religious box -- that we are all, everyone of us, imprisoned in.[44]

<u>"Distance learning takes away from personal contact, the key value of PME."</u>

First, even without the existence of the virtual reality of 2020, current connectivity has already demonstrated that interactive communication through electronic means may lead to even greater openness and understanding than face-to-face communication. This is due to the entirely egalitarian nature of the interaction, which eliminates many of the intimidating and inhibiting factors of face-to-face in-the-same-room communication. For example, one of the top "head hunter" executive recruiting firms, as a cost-cutting measure, in 1993 began providing video conferencing technology for client companies to use for interviewing top-level candidates, a situation where "every nuance of face-to-face

communications is crucial." The vice-president of the recruiting company said they were surprised at how quickly client companies adapted.

> Initially we thought they would interview candidates and then fly in the final candidate, but in many cases candidates have accepted the job right over the ConferView. They were more comfortable than we thought they would be.[45]

Interpersonal skills apparently are communicated over the electronic medium. Coincidentally, the above firm estimates it will save clients $135 million this year in reduced travel costs.

Second, by 2020, virtual reality will provide the stimulus of co-location. MIT already is working on computers which will read subtleties of facial expression and voice and duplicate them on computer-generated representations of individuals involved. MIT researchers are even teaching the computer to recognize the difference between a genuine and fake smile.[46]

Third, the virtual classroom may be supplemented, at least at first, by a physical meeting of the participants. This meeting will likely be of a short orientation nature. For example, designated virtual seminar mates, spanning services and nations, may meet for two weeks of immersive orientation at the beginning (and perhaps annually) of a three-year virtual seminar course. This physical meeting should enhance and personalize to the computer representations of each of the seminar members. Even today's virtual reality simulators already allow participants to quickly dismiss any lingering artificialities. Bruce Sterling reported on Army tank crews and their virtual reality experiences.

> Group by group, the dead tank crews filed into the classroom and gazed upon the battlefield from a heavenly perspective. Slouching in their seats and perching their forage caps on their knees, they began to talk. They weren't talking about pixels, polygons, baud-rates, Ethernet lines, or network architectures. If they'd felt any gosh-wow respect for these high-tech aspects of their experience, those perceptions had clearly vanished early on. They were talking exclusively about fields of fire, and fall-back positions, and radio traffic and indirect artillery strikes. They weren't discussing "virtual reality" or anything akin to it. These soldiers were talking war.[47]

"Distance learning (or virtual residency) reduces student interaction with the faculty."

Figure 12. Virtual Interaction

The facts argue that increased connectivity will mean even greater interaction with faculty, with more efficient use of student and faculty time, by using multi-party interactive on-line or virtual conversations. In addition, there will be increased access to experts not on the "resident" faculty, but merely available to answer questions in their particular area. This is a critical aspect of PME 2020 when one considers future reduced numbers of military experts and reduced funds for hiring full-time civilian (including retired military) experts. Will PME schools and courses be able to afford full-time subject matter experts for each particular weapon system, culture, or strategy? The virtual residency, expert systems, and telecommunications aspects of PME 2020 guarantee these experts, or at least their knowledge, will be available for the future war fighter on-demand.

Additionally, using virtual reality, students can talk with Caesar and Napoleon. These "virtual" leaders will be programmed with all the anecdotes, paintings, photos (if available), film, video, and books about them. MIT and other labs are working on programs to create "virtual" people that seem alive in virtual reality environments. At MIT the project researching this is named, appropriately, ALIVE.[48] Children's games are already using the beginnings of this technology to introduce students to historical figures. To reduce artificiality , computer software makers in Japan are now producing interactive computer programs where the characters' lips are in synch with the words they speak.[49 50]

"Let's slow down and fully study this before proceeding any further."

The technologies discussed in this paper will be available and will be used, either in a well-planned manner as outlined in this paper, or in an after-the-fact reaction. These

technologies will be useful and necessary, regardless of what mix there is between physical residency and virtual residency. If pre-implementation studies show there is indeed some unique aspect about the 10 1/2 months of the current resident program that cannot be simulated by the virtual residency program, the military can always retain a portion of the program as it exists today or modify it appropriately. For instance, they can be replaced with the 2-3 week (or possibly longer) orientation TDY mentioned earlier where faculty, students, and key subject matter experts all meet each other so the virtual representations used later will have additional meaning behind them, adding to their realism and suitability.

Conclusion

The proper use of emerging technology will allow us to effectively deal with the incredible increase in new information with fewer financial and personnel resources in a more demanding technological environment. Therefore, all military personnel and organizations must be connected to the PME 2020 system. PME institutions must be the first to change, to set the pace rather than react. It will not be easy.

Paradigm shifts will be required. We will have to rethink what roles the computer, telecommunications, and virtual reality will have in the PME system, and what will be expected of the individual in the system. This will consequently require a new approach to education and training. To initiate these paradigm shifts, we must market the benefits of creating a more responsive PME system.

In the final analysis, we have four customers to convince of the relevance and suitability of the PME 2020 concept: the PME students (individual war fighters), the students' commanders, the faculty, and the Service chiefs. If all of the above customers cannot be convinced, then PME 2020 will fail as have so many initiatives in the past which lacked top-to-bottom support. Military education will then default to a reactive mode, continually behind the demands it responds to -- instead of anticipating and planning for the needs of its customers, customers who will themselves be reacting to the challenges of a continually changing and increasingly overwhelming information and technology environment. PME must begin to respond to the information and technology explosion, take advantage of the future characteristics of military members, boldly push

forward despite fiscal constraints, and take advantage of the changing technological environment.

Potential Technologies

Introduction

Overall, technology is one of the two main factors necessary to meet the capability requirements of PME 2020. The other is a change in the policy and processes. While technology developments will determine the possible ways of delivering education, educational policies and processes will determine: 1) who is educated (everyone or a select few), 2) when military members are educated (at a specific time for all or at the appropriate time for each individual), and 3) where military members are educated (in-residence or through virtual residency).

Will the technology exist to support PME 2020 as envisioned in this paper? Trends in technology today, in general, indicate the necessary capability will be both available and affordable. Many of the technologies needed are already in use or under development. However, there are hurdles and resistance to overcome in successfully implementing the PME 2020 system.

Needed technologies will be available

The technology of 2020 is not a limiting factor for implementing any ideas we have in 1994. For instance, comparing the 64K RAM computers of the early 1980's with the top-of-the-line desktop computers of today, we have witnessed an over 1000-fold increase in computer memory. This increase follows Moore's Law, a rule-of-thumb coined by one of the founders of the Intel Corporation. This rule states: the number of transistors on the main microchip in a desktop machine will double every two years. So far the rule has been remarkably accurate. [51] Since the number of transistors is a rough measure of computer power, the military can roughly predict its desktop computers in 2020 will have about 16,000 times the power of today's computers.[52] This prediction is considered a conservative estimate by many industry experts. Some predict the computers of the next century may have billions of times more power. Some believe Moore's Law describes only the slow beginning of a curve which is becoming increasingly steep. Others believe

Moore's Law doesn't take into account the coming revolutionary replacements for the transistor. These new devices will squeeze even more power onto whatever replaces the computer chip. In other words, industry experts agree, the military will have plenty of power for whatever it may dream up in 1994. Project 2851, a new standard for digital terrain, is already facilitating automatic transformation of satellite information into 3-D virtual landscapes.[53] Extensive telecommunications, virtual reality, and computer simulation for PME 2020 is assured.

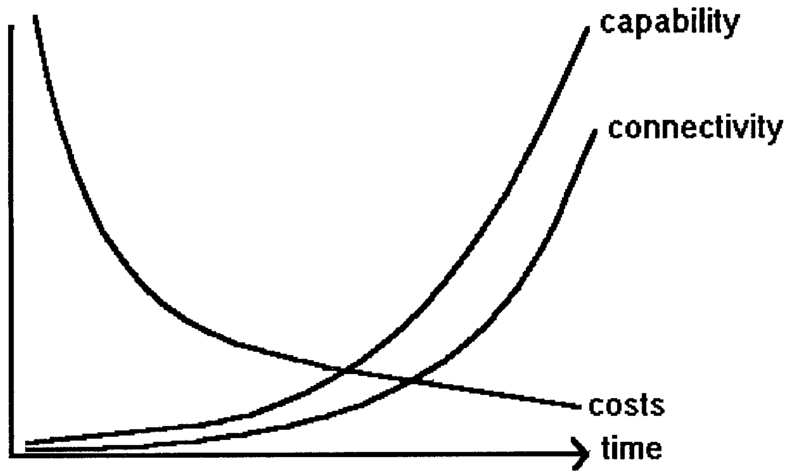

Figure 13. Continuing Trends

PME 2020 Will Be Cost-Effective And Affordable

The next question then, is whether PME 2020 will be able to afford the technology it needs to meet capability requirements. Again, analysis of today's technology cost trends predicts the future costs. Currently the price of computing capability is reported as declining between 30 and 68 percent per year. The rate cited by the ABC Evening News of 50 percent reduction every 18 months is a conservative estimate. But even using this rate, if the military wants to determine what capability it will be able to buy for each office or classroom for $5000 ('94 dollars) in 2020, it should look at the capability that $655,360,000 [54] could buy today. Imagine the technology that might be purchased in this price range for each classroom or each individual. Even if no new technologies were to develop between now and 2020 (though highly unlikely), being able to use current technology in this price range would mean a significant difference in the office, home, and school. To be able to plan effectively, the military education system must unshackle its mind from today's limitations. Possessing technologies in this price range will give military members greater technology on their desktop than that which currently produces all the

special effects in the latest science fiction movie. It will give each student's computer greater simulation capability than the latest simulators now used by the airlines or military, with surround picture and close-to-reality simulation. The technologies needed for PME 2020 will definitely be affordable.

Specific Technologies

Today's existing technologies also provide some specific examples and insight of what is possible in 2020. These potential technologies will solve the information, people, fiscal, and environment problems of PME 2020. For example, potential technology exists today to solve the information overload problems of tomorrow. Human - computer interaction devices will also aid the war fighter in this area of information management. In addition, both virtual reality and worldwide instant access are assured.

Information Overload Solutions

As previously discussed many current military personnel already belong to wide area networks such as Internet and bulletin board services such as Compuserve. These connectivity providers are currently developing the next generation network technologies. This includes automated aids used to find information and people over the networks. These automated aids are the beginnings of personally tailored automatic assistants. PME 2020 automatic assistants will help us navigate the information highways without becoming overwhelmed. Edify Corporation has announced their "Information Agent," which give users the ability to train computer networks to automatically gather and analyze data based on use demands.[55] Professor Negroponte, founder of MIT's Media Laboratory, stated: we will soon have personalized "newspapers" coming over the computer networks, with not only the news, but also the ads, aimed at the individual.[56] Automated assistants with even greater capabilities will be used by the PME 2020 system to ensure each individual receives the most current and relevant information -- tailored to his or her needs and background. But even with such assistants ensuring the information military people need is available, PME 2020 must teach the skills to find and use it appropriately.

Virtual reality itself is being used as a solution to the information overload. One method of employing virtual reality as a "database navigating and mining tool" is used on Wall Street for managing stock portfolios. It uses a virtual world in which stocks and

groups of stocks are represented by symbols of different color, shape, position, motion, and other characteristics. This enables a stock portfolio manager to use the computer to generate patterns and color changes that summarize at a glance the health and trends of many more stocks than could be managed as well by flipping through files or complex computer screens with tables of numbers.[57] It is easy to see how this type of an application will be used to summarize much of the data that threatens to overwhelm the military person. This technology can be used by the PME 2020 system to search through the information highway and determine automatically many of the needed updates to curriculum materials.

Human-Computer Interactions Will Be Enhanced

The PME 2020 system will benefit from enhanced human-computer interaction. In 1993 these interactions already included full-body suits for gesture and other motion detection[58], computers embedded in clothing,[59] and experiments in controlling computers by thought. Regarding the latter, the Alternative Control Technology Laboratory at Wright-Patterson is making significant advances in mental (hands-off) control of flight simulators. Grant McMillan, director of the lab, stated:

> All control is brain-actuated control, as far as we know. All we're doing is measuring the output at a different point ... Twenty or thirty years from now, we might be saying, "Gee, I'd never want a pilot to control the stick with his hands when he can do it so much better by manipulating his brain activity."[60]

Military developments in hardware, software, and even "wetware (the implant of technology directly into the body)," are discussed by Manuel De Landa in his book *War in the Age of the Intelligent Machine*."[61] These upcoming technologies will ensure unprecedented realism in the virtual residency environment of PME 2020.

The military services are actively developing artificial intelligence and expert systems to aid humans to digest information and act on it. For example, expert systems have been developed for analyzing radar signatures, labeling automatically generated maps, analyzing battlefield situations and air-to-air encounters (from command level down to helping an outnumbered pilot survive an engagement), planning for contingencies, diagnosing maintenance problems on aircraft, playing the role of intelligent opponent in war games, developing attack strategies for complex targets, helping to detect and counter

C3 countermeasures, providing advice on allocation decisions, assisting launch and recovery on carriers, and even predicting likely locations and times of outbreaks of violence.[62] Artificial intelligence and expert systems will enable PME 2020 to provide whatever information is required whenever it is needed.

Virtual Reality Will Be Commonplace

Figure 14. From an Ad for Virtual Reality Eyeglasses

Nintendo is already reaching into the home with first-person virtual reality games. Already available are virtual reality eyeglasses with built-in stereo sound systems, similar in appearance to regular sunglasses.[63] Also available is software for less than $1500 to build individualized virtual reality worlds, or a head start can be gained by buying prebuilt worlds for $90 - $400 each. Although these inexpensive hardware and software systems don't currently match the movie studio multi-million dollar systems, "they're sparking creative breakthroughs ... and they're helping to drive the development of an industry, a communication tool, and the ultimate multimedium."[64]

By 2020, virtual reality, or whatever its follow-on is called, will be ubiquitous. Military personnel will be used to the technology and to the capability it provides, a capability that will be a natural part of their lives -- through uses such as the Nintendo games mentioned above. Thus, by 2020, military personnel will have virtual reality expectations -- expectations which will depreciate or reduce effectiveness of any military education which fails to use the learning interface to which the students are used to. To avoid being placed in a reactive catch-up mode, military educational institutions must take steps now to become proactive -- leading the way, instead of being dragged, into the next century.

If you tell me, I'll listen.
If you show me, I'll see.
If I experience it, I'll learn.
- Lao Tse, 430 BC

To my astonishment I was informed on leaving college that I had studied navigation! -- Why, if I had taken one turn down the harbor I should have known more about it.
- Henry David Thoreau

The importance of virtual reality cannot be overemphasized. The reasons for using interactive technology education are many, and evident from discussion elsewhere in this paper. A few are listed below.

- Experiential learning. First and foremost, interactive technology takes advantage of the strengths of this type of learning, so eloquently stated in the quotes above.

- Flexibility. When well-constructed, interactive technology lessons allow for tailoring of lessons to the individual, the individual's learning style, and the job at hand. Updated information can easily be dropped into the lesson and, if using a direct mode of delivery, is instantly available without waiting to deplete last year's printing.

- Timeliness. Available on-demand. Doable in small chunks which fit the student's schedule. Redoable and reviewable, as in remediation. Takes up less time overall.

- Student centered. It can be self-paced and take advantage of the student's existing knowledge -- teaching in the gaps. It can also provide personalized immediate feedback for everything the student does or asks.

The military has already laid the foundation for the virtual reality world of the future. For example, Navy, Marine, and Army hospitals worldwide already use an interactive video, text, sound, and graphics system for training medical personnel about combat trauma life support and preventive medicine in combat zones.[65] The applications of virtual reality to the multimedia environment are limitless.

> Virtual realities are a multimedia environment that gives users the sense of participating in realities different from their ordinary ones ... Such simulations, when done well, should provide to a user a sense of having a life-experience: learning occurs at an essential level, a fundamental change in attitudes and behavior results.[66]

The author of the above statement, Joseph Henderson of Dartmouth Medical School, also describes virtual workplaces, with virtual colleagues, whose "physical counterpart may exist in any of the far-flung problem-solving teams deployed anywhere in the world." These virtual coworkers will meet and work in virtual hallways, virtual conference rooms, and virtual laboratories.

> One can as easily imagine a virtual high school, technical school, or university, which provides access to information and expertise that is anywhere in the world. Even difficult concepts, skills, and attitudes might be taught using vivid, three-dimensional and tactile representations of real world objects and issues. This kind of learning environment could be embedded in the work environment (even a non-virtual one) much as today's new performance support systems provide on-line training and reference on the assembly line. The worker need not leave his or her workplace to be trained; organizations need not establish and support fixed training facilities and travel costs can be reduced. Learning done in direct context with work is likely to be more efficient and effective.[67]

Virtual reality, or "synthetic environments," was listed in 1992 as one of the seven main technology thrusts by the Pentagon.[68] Victor Reis, DOD Director of Defense Research and Engineering, stated, "the demands of fighting on those battlefields [of the future], will be radically different from today's." He also stated: "Synthetic environments represent a technology to let us learn how to use technology better. It's that feedback loop that does it." Reis had recently testified: "network simulation is a technology that elevates and strengthens the collective problem-solving abilities of ... design teams, manufacturing teams, education teams, training teams, acquisition teams, or war fighting teams." Finally, he pointed out: "another benefit" of the synthetic environments is "cost reduction."[69] For all of the aforementioned reasons, virtual reality must be part of PME 2020.

Instant Access Will Be Assured

All military members will be connected to the PME 2020 system and instant access to the system will be assured. New Jersey Bell plans on having all of New Jersey completely fiber-cabled by 2010.[70] Other companies in the US and "in most industrialized nations" are planning on doing the same, or in some way providing the same level of connectivity.[71] For those areas, however remote, which will not be interlinked with cable,

space will provide the same functional connection, through satellite links. Commercial enterprise will send into orbit a constellation of satellites which will enable instant contact anywhere on the globe, "a cellular system with very tall towers called satellites."[72] PME 2020 can assume worldwide two-way access to all military personnel in 2020.

Hurdles To Overcome

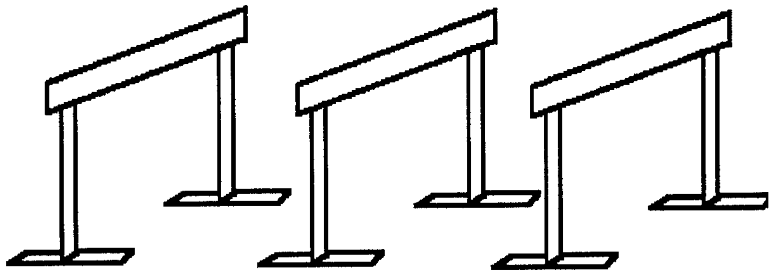

Figure 15. Barriers to Progress

Hurdles to overcome include current regulations and manuals, which have yet to adapt to the rapid change of pace to which we must acculturate ourselves and the PME system. Also, due to funding limits and personnel limits, the military frequently finds itself behind in many areas of adopting the best (not necessarily newest or fastest) technologies to its needs. If the military is to progress toward a primacy of continuing career-long education through virtual residency, it must determine this now, and then develop the enabling infrastructure to channel its efforts.

<u>Hurdles For Virtual Reality</u>

What are the most common reasons given for not using interactive technology or for resisting its inclusion in educational programs? According to a study[73] by the Business Research Group of Newton, MA, the following were the obstacles to implementing multimedia applications:

Cost	51 percent
Equipment	19 percent
Lack of expertise	13 percent
Training	11 percent
Lack of industry standards	8 percent
Management resistance	7 percent
Time	6 percent
Inadequate applications	3 percent

No obstacles	9 percent
Other	4 percent

As previously discussed the equipment will be affordable. As the equipment becomes more user friendly, lack of expertise and training will be less significant. Industry is currently developing the standards. Therefore, resistance will be the most significant factor. Once again, promoting the advantages and applications of this technology is the only way to overcome the mind-set. For example, a survey of national business leaders and trainers, regarding what methods best improved 41 key business skills, revealed 32 of the skills were best taught using experiential exercises and/or simulations. Lecturing was judged best for one skill, listening reflectively. The remaining eight skills were judged best taught using case studies (which also could be done very easily in the virtual seminar environment). The business leaders also rated the skills in importance. The four top-rated skills (adapt to new tasks, make decisions, organize, and assess a situation quickly) were all considered best taught by simulations.[74] But even with demonstrated strengths of the methodology and technology, there will still likely be resistance on at least some level.

Resistance, Need For Champions

Del Wood, IBM design specialist, stated that among the Fortune 500 companies he has helped implement multimedia, he has frequently encountered two types of resistance. One type was due to intolerance of delayed gratification, as the users must wait for the payback on investment until after development of lessons and schedules. The other type resistance was due to "a fundamental human aversion to change," caused by multimedia lessons requiring a different set of skills, orientation, and commitment.

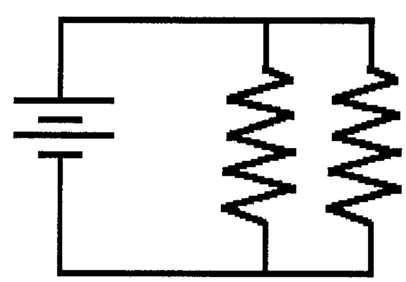

Figure 16. Overcoming Resistance

Mr. Wood pointed out: because of the diverse skills and resources needed for good interactive courseware, "it requires multiple champions and visionaries to implement a change...."[75] This need for champions is one the military must address. By fostering a continual, though gradual, conversion of methodologies as the military education system marches toward 2020, the system will grow the champions as the interactive system grows.

Conclusion, Action Needs To Start Now

The military needs to immediately establish at least a temporary home for a central repository of military and civilian research and proposed solutions regarding questions raised in this paper about potential technologies. Air University (AU) can be that initial repository. PME 2020 recommends AU establish an on-line list of names of who is researching PME-related areas. AU can develop this central repository and on-line capability with current technology, needing only computers, large storage devices, and on-line connectivity for incoming and outgoing information and questions. As the military builds toward PME 2020, there will be a continual need to know what the most promising upcoming potential technologies are and how best to apply them.

Near Term Technologies and Operational Exploitation Opportunities

> "Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur."
>
> \- Giulio Douhet

Introduction

A successful PME 2020 system depends upon taking advantage of existing or emerging technology and operational exploitation opportunities. The military must now begin planning for PME 2020. First, an office of primary responsibility must be appointed to oversee and implement the changes. Second, working groups must be formed to recommend changes to the PME infrastructure. Third, emerging technologies need to be monitored constantly, watching for developments which might aid PME programs to educate military members how to effectively and efficiently manage the coming flood of

raw data. Finally, the path to a successful PME 2020 will depend upon the quality improvement process to generate better ways to perform the education mission. In fact, some organizations have already started to shift direction to take advantage of the near term technologies and the operational exploitation opportunities they afford. However, the annex provides the steps that must be taken to start the military on the path to PME 2020. To ensure a successful PME 2020, the system 2020 must initiate changes now in a planned evolutionary manner, not waiting to be overcome in a chaotic, unplanned revolution of de facto changes.

NOW!

If the PME system fails to plan, then the resulting unplanned implementations will hamper progress and fail to provide the education required for future military members to become the force multipliers the nation will need in 2020. The best way to integrate new technology and processes into the PME system is to appoint a responsible office of primary responsibility (OPR) to oversee and implement these changes. This "OPR" will also be a liaison between the PME system and civilian education systems and emphasize usability and commonalties to both worlds. Furthermore, to meet the expected challenges and opportunities discussed in this paper, the OPR needs to initiate a restructuring of the PME infrastructure to bring it in line with the rapid changes in educational requirements.

Infrastructure

The PME 2020 infrastructure will be different than that of today. The first requirement for initiating infrastructure changes is continuing to research the educational and technological environment and determine which structures will lend themselves best to rapid adaptability to technology. PME working groups made up of various career fields, having a variety of skills and interests, need to be formed to serve as the initial catalyst for the forming of PME 2020. They will recommend what funds are required to purchase technology. They will develop points of contact at military and civilian institutions and both groups will share in the discovery process and act as funnels for discoveries as they happen.[76]

Emerging Technologies

Emerging technologies need to serve, not dictate, the development of instructional PME programs that will educate people to effectively and efficiently manage the flood of raw data. Also, technology already exists which presents the opportunity for people to work and interact together even when geographically separated. Taking advantage of these two technologies is absolutely essential. Col. Jack Thorpe, special assistant for simulations at the Pentagon's Defense Advanced Research Projects Agency, stated, "We will expect a smaller military to be masters of a wider ensemble of skills. This (interactive simulations) is an idea whose time is right." He pointed out how using this technology drastically improved tank crews scores on real-world tests.[77] As military resources decrease, the need for military and civilian personnel to maintain connectivity to ensure pooling of resources, whether physical or cognitive, is paramount.

Telecommunications

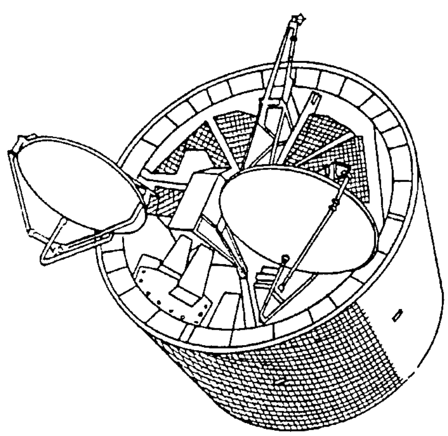

Figure 17. The High Ground of PME 2020

Initially, the military must employ existing telecommunication technologies in PME. This will involve the integration of present stand-alone telephone, audio, television, computer, and satellite communication systems with interactive video capabilities and real-time access to the emerging Information Super Highway and other information-rich nodes such as the Library of Congress, colleges, and universities. The military must also be prepared to take advantage of future technologies in this area. By 2020, some future form of artificial intelligence technology will be part of the 2020 version of a telecommunication system.

The benefits of telecommunications will be immediate. PME's support and harnessing of integrated telecommunications will encourage individuals and groups to pursue a variety of interest areas. Personnel will be better prepared for smoother transitions between phases of one career, or between completely different careers. Comparatively speaking, this will place military personnel in a better situation than their civilian counterparts, since experts predict individuals will hold multiple careers in the future. The military organizations, as a whole, will benefit as well. If its personnel understand a few to, perhaps, several different areas, this increase in knowledge will directly contribute to, and enhance the military's flexibility to adapt to massive changes in organization, mission, and emerging technology. More importantly, this knowledge will increase the military's flexibility to adapt to any crises. Overall, people with broader backgrounds will better augment a crisis management team. Therefore, PME needs to harness the changes emerging technologies bring about. Telecommunications is just one of many emerging technologies. Human-computer interface is another.

Human-Computer Interfaces

The PME system must begin investigating devices that aid in the "knowledge" level of information. Continual connections and computers responding to thoughts (although limited at this time)[78] are only two examples of emerging, evolutionary technologies which are allowing knowledge level information to become largely the responsibility of computers vice the responsibility of individuals. Regarding continual human-computer connection, "nearly every major computer company is currently developing wearable hardware. ... The Tender Loving Care PC for paramedics features a screen embedded in a pair of high-tech glasses and a hand-held sensor to measure the patient's vital signs."[79] These devices may not have an immediate application for the PME system, but they will have an impact on it, nevertheless. PME must train individuals to properly use these devices and manage the information they can provide.

Quality

PME 2020 will depend heavily on the quality improvement processes. It will generate discoveries of better ways of performing the education mission. This will result in saving dollars and saving lives throughout the Department of Defense (DOD). In the Air Force Quality Institute's call for papers for their October 1994 symposium, they

include education and training programs as key elements of the "Quality Air Force in the Year 2000" sub-theme. Another major theme of the conference is "The Advanced Workplace in the Year 2000." Key elements include items directly related to the PME 2020 system: improved executive decision-making, creativity in the workplace, "personal continuous improvement (training and education)," how to facilitate change, "professional development," and the "learning organization."[80] These are all concerns of PME 2020. The quality improvement process will provide the insight required for a successful transition to PME 2020.

Take The Lead

Some organizations have already started to shift direction to take advantage of the new technologies. The Air War College Organizational Plan includes initiatives for a teleconferencing capability and for an interactive simulation link between the senior service schools. However, money is still needed to implement these initiatives. Also, the scope of these actions needs to be extended. The justification for the interactive, linked capability applies to personnel other than just the senior officers, and to subject matter other than just wargaming:

> Given the mandated decline of precious resources and personnel, it is in the best interest of our nation to provide our officers with every opportunity to practice in peacetime the combat decision-making they must employ in time of war. As war fighting continues to become more complex, senior leaders need experience translating national level decisions into operational action. This exercise of operational art requires not only development of plans and campaigns, but more importantly the opportunity to manage and execute those plans and campaigns. Educational wargaming provides this vitally important opportunity, and because it is process oriented, it improves war fighting, combat decision-making methodology. Compared to costly field training exercises, wargaming can provide a low-cost and certainly more efficient environment wherein officers can practice in peacetime the skills they will need in combat.[81]

Conclusion

The April 1994 issue of *Popular Science* recalled an issue 100 years ago wherein a professor from the University of California retracted his 1888 statement that self-propelled flying machines were "impossible." Instead, he now said, "while possible, the

engineering difficulties are enormous and possibly insurmountable." Nine years later he was proven short-sighted at Kitty Hawk.[82] If we fail to take steps now to prepare for what technologies and processes must be developed for future education and training programs, we too will be viewed in future years as short-sighted. Unfortunately, short-sightedness in the Professional Military Education system will mean loss of lives and national power.

Our military forces will be much smaller in 2020 yet the world will be a dangerous place. In addition, space will be added to the land, sea, and air as a conflict medium as competition among nations in space increases. This environment, coupled with the information explosion, the changing characteristics of military personnel, fiscal constraints, and significant technological advances will require a much more educated and trained force if America is to remain a military superpower in the twenty-first century.

Implementing the concepts outlined in this paper will mean taking the first steps in initiating a flexible, adaptable, up-to-date, state-of-the-art, military education and training program which is able to respond to the challenges of the world of 2020. This paper has identified the subject and problem statement, the capability and its relevance, potential technologies, and near term technologies and operational exploitation opportunities. All must be understood and acted upon for the US military to continue to fulfill its unique national security role in the future. The primary method of ensuring PME 2020 is relevant to the war fighter is through the efficient and effective use of leading edge technology. These technologies will be used to accomplish military missions, but they must also be used for PME as a force enhancer. Colonel John A. Warden III, Commandant of the Air Command and Staff College, summarized the concept of PME 2020 best when he stated: "PME must be on the cutting edge of technology if it is to survive as an institution in the future."

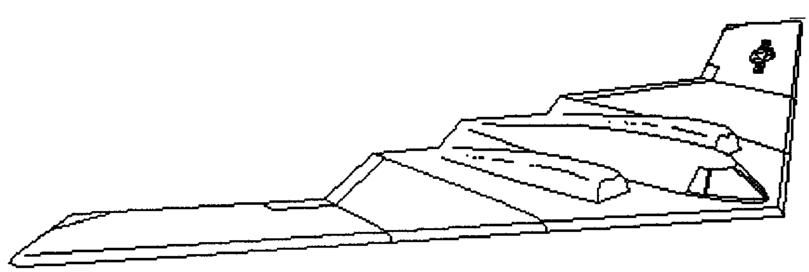

Figure 18. PME 2020

Annex A: Steps to Take Now

These are steps which must be undertaken immediately to start the military on the path to PME 2020:

1. Protect the sources of future research by immediately stopping the creation of hard-copy (printed) only documents and publications at military institutions of learning and research. At a majority of the Department of Defense schools and publishing agencies contacted by the authors, there is no current policy to even keep the disks which are used by the printers to generate books and articles. When demand exceeds the print run, retyping and reproofing are then required. [83]

2. Begin the process of putting all books and research papers on-line for easy access to both military and civilian researchers and for access in day-to-day operations in case the information is needed on-the-job. But, until the access plan is developed, and the hard disks or other storage acquired (it may be as simple as putting all text on CD-ROM's), the very least the military needs to do now is to declare a halt to the routine disposal of the electronic copy of published texts. The longer the military waits to accomplish this step, the more texts will have to be scanned or retyped in order to make them electronically accessible once more.

3. Standardize, maintain, and enforce the skills required in the world of 2020 by immediately requiring all PME attendees to either take technology orientation courses, or "test out" of them. If military decision makers do not understand the power of the technologies available to them, they cannot use them effectively, or even provide their fair share of ideas and innovation for making maximum use of technology. These orientation courses will cover as a minimum the following:

- Computer basics, such as how to copy files to and from floppies and hard disks. This will facilitate transferring projects between offices, organizations, conference room projection systems, bases, classrooms, and home.

- Databases: what are they, how do you make them and maintain them, and what can they do for your organization?

- Spreadsheets and financial planning software: how do you use it to better understand budgeting and procurement?

- On-line connectivity: how do you use local area networks, wide area networks, research networks, and on-line data sources?

- Presentation software and design: how do you get maximum impact in presentations, but spend minimum time designing the slides? What are the ergonomics of good presentation. For example, what are the best colors to persuade, screen designs to avoid, best timing and phasing of slides, and appropriate accompanying text.

- Job-specific software for particular career fields (an elective -- strongly encouraged), such as computer-assisted design software.

- Expert systems and artificial intelligence applications: what are they? Where can you find ones that will help with your field? How do you build new ones to help with manpower shortages by multiplying the productivity of those people you do have?

- Electronic performance systems, such as interactive scheduling, personnel management, tutorials, and tailored information management aids.

4. Re-emphasize the status of PME institutions of higher learning by establishing them as centers for solutions to real-world problems. Have more "think tank" type studies by military for military -- and save money as well. Build on the experiences from SPACECAST 2020 and begin immediately to link all the education centers within the military and then link them to civilian institutions. When military members encounter problems they will know EXACTLY who to turn to first to find the answers--Air University, NDU, or whoever is selected as central point of contact. The PME network will include names, organizations, and phone numbers for every type of problem military members have encountered. New references will be added for each new problem and answer.

This is a program which could start happening immediately. The equipment and processes used for the SPACECAST data call could be used to expand the database of resources to include these other areas of interest. An interactive on-line forum could soon elicit the names and numbers of many other references. During SPACECAST there was at least one prominent example of the benefit from this type approach: when two research teams within DOD discovered they were working on the same project -- "discovered" because each found out through contributing to SPACECAST that the other existed.

5. Encourage local units to develop their own PME and OJT programs by recognizing local program development for the asset it is. Civilian publications continually emphasize this "downsizing" or "rightsizing" of hardware and software technologies. The military must also maximize use of these technologies. This effort includes new development tools which allow individuals with little formal training in computers to generate their own training and management programs. This locally-initiated development is actually becoming widespread in the military as well. Today, military members are using such tools as Asymmetric Toolbook and Hyperwriter and Icon Author to develop local training and education applications. Air University and other military education centers should be taking advantage of the subject matter expertise, programming skills, and enthusiasm shown by these individuals. The following are examples to encourage this type of innovation.

- Provide military members with a forum to showcase their solutions, and possibly solve other people's problems. Examples include a central clearinghouse of programs (such as the former C2 MUG group of several years back in the Army), an on-line bulletin board for sharing solutions, or a column in the Times group (Air Force, Navy, Army, and Federal) of military newspapers.

- Provide military members with the guidance to develop the best possible education and training program. This will include a compilation of research by Armstrong Labs and others on ergonomics of screen design, equipment arrangement, and methods for interactions. It will also include guidelines on how to test students on-line, how to steer student progress through on-line lessons, and how to present lessons to maximize carryover to real-world use.

- Maximize the potential sharing of these locally developed educational and training programs. Provide guidelines on how to design applications that incorporate reusable blocks of instruction, which can easily be updated with new information and doctrine. Then provide an exchange method so military members using the same development tools can swap the procedures and routines they develop.

- Encourage innovation in educational and training by eliminating constraining requirements that, while possibly good for service-wide applications such as supply or procurement procedures, limit local initiative. The civilian sector has discovered there is no one developmental tool which works for all problems all the time. As the military is certainly as complex an organization as the largest of any civilian company, this same discovery lesson applies to the military as

well. For example, most computers applications include their own development "language." Requiring all programmers to use Ada, or undertake a lengthy waiver process will discourage innovation. Additionally, military constraints which unnecessarily differ from civilian norms will limit the spin-on and spin-off possibilities.

- Include the best solutions to education and training problems and the names of the authors as part of the central answer database mentioned earlier. Participation in all military efforts will improve if people feel they are receiving useful products or information from the system or are receiving acknowledgment for contributing the information to the system.

- Build on the two-way theme espoused by Gen. McPeak and others. Require all PME participants work on solving real-world problems when they do research. When solutions are found, direct them to the decision makers who will be able to implement them. Highlight these solutions by submitting them to the Military Times series of newspapers. Explain the problem and the solution and how readers can obtain copies, help, or contribute their own lessons learned and better solutions.

6. Continue monitoring the development of the new future technologies by routinely polling leaders in the educational technology field. Maintain the status of those technologies they believe are most important for the future, closest to development today, and those in need of the most research. The goal is to be constantly aware of the best technologies with the greatest potential to match education solutions with on-the-job problems of the next century. Finally, establish a military OPR for each technology. The OPR will be responsible for answering military members' questions concerning the technology, maintaining contact with military and civilian researchers in areas directly impacting on the maturation of the technology and its application, and keeping up-to-date the on-line accessible resource list regarding that particular technology.

7. Begin the process of connecting institutions to the PME system by establishing a direct link between all research institutions, labs or staff colleges, in the military,. This link will serve as the means for achieving synergism between researchers, educators, and users of research results. Flatten the information distribution pyramid. Information must be shared at all levels between all organizations. Information must not be "stove-piped." As Tom Peters states in *Thriving on Chaos*:

> We must pursue fast-paced action at all costs, and therefore: (1) Vigorously and gleefully, with all hands participating, take the lead in

> destroying the trappings of bureaucracy. (2) Manage the organization "horizontally" - that is , insist that "vertical " obfuscating be replaced with proactive (no checking "up"), "horizontal," front-line cooperation in pursuit of fast action.[84]

8. Prepare for the classroom of the future by beginning to re-engineer it. This concepts involves more than just adding technology to the classroom. It means the military must also change the processes and methods of education.

> For 25 years ... the growth in productivity for workers surrounded by computers was dismal. The reason? Companies were trying to automate the same old paper processes. Only in the past few years, when businesses began "reengineering" fundamental activities -- opening wide swaths of their business to new approaches and reorganization -- has the technology begun to pay off.
>
> ...today's stultifying [education] system stems from a 20th century impulse to systematize learning and give the classroom some assembly-line-like efficiencies.
>
> Today the useful parallel between running a business and running a classroom may be in the way technology can empower individuals. In many corporations, advanced computer networks have given workers at all levels access to critical information. The effects can be invigorating: employees gain autonomy and take more responsibility, organizational charts flatten, and enterprises become more responsive and efficient.[85]

Remember, "resistance" will be expected from the "education establishment," especially after considering the frustration of trying to implement technologies in the classroom in the past.[86] We have to show, not just tell, today's educators the advantages of the education system of the future.

9. Incorporate the emerging technologies immediately by taking advantage of educational technology advances in the civilian community. "Indeed, the Info Highway could spur huge demand for interactive educational software."[87] Yes, it already has, as evidenced by the burgeoning selections of CD-ROM and multimedia simulations, first-person virtual realities, and interactive programs for the education market. One software catalog alone has over 550 CD-ROM titles available, many in the first-person (a precursor to the virtual reality of the future).[88] Among the titles are disks on Desert Storm, the CIA World Fact Book, World and US Atlases, "Twelve Roads to Gettysburg," the space shuttle, several

on space imagery, US History, cultural disks on specific countries and regions, the building of the Berlin Wall, and numerous disks on foreign languages and science. The information wave has begun.

10. Begin the process of connecting individuals to the PME system by operating education and training electronic bulletin boards at Air University and corresponding locations in the other services. All bulletin boards will be linked. All will be accessible through both DDN (using a modem) and through Internet (for those service members who are fully networked). Sections of the bulletin boards will include discussion areas, research areas, information "posting" areas, and sections that groups will use for specific projects and working together (the precursors of the future virtual seminars). The interactions between military members in these sections will contribute to initial studies determining the benefits to be gained and the problems to be solved with non-collocated workers and students. Those studies will then be used to help make the necessary decisions as the military progresses toward the methodologies, technologies, and psychology of the virtual classroom and university.

Annex B: Curriculum

The question is in two parts. First, what will the future curriculum include? Second, will multimedia and virtual reality fit into PME 2020's curriculum?

What Will The Future Curriculum Include?

The PME 2020 curriculum spectrum is likely to include the following , in various combinations and sequences:

Technical Training, by System and Career Field
World History 101 - 505
Military History 101 - 505
Military Theory 101 - 505
Strategy 101 - 505
Quality Principles and Methods 101 - 505
Space 101- 505
Non-lethal Warfare 101 - 505
Information Warfare, Defense and Offense 101 - 505
Weapon Systems, Design and Use (assorted)
Capabilities and Methods of Sea, Land, Air, and Space Forces
Logistics and Combat Support 101 - 505
Intelligence, Gathering and Using 101 - 505
|Technology Update (may be repeated often)
Group and Team Dynamics 101 - 505
Personal Optimization, Maximizing Your Potential 101 - 505
Creativity and Innovation 101 - 505
OODA Loops and Other Mental Force Multipliers 101 - 505
World and US Political Systems 101 - 505
International Relations and Regional Studies 101 - 505
Culture and Its Impact on Warfare 101 - 505
Foreign Languages (important with regional responsibilities)

Will Multimedia And Virtual Reality Fit In It?

One of the key issues concerning educational technology was expressed well by Maureen Arnead of Berlitz International:

> Turning now to foreign language learning, will IMI (Interactive Multimedia Instruction) really bring about a revolution? Will it be worth the effort to use the medium? The language teacher is still suspicious -- bad

experiences in the past with the much- heralded Language Lab (most of which are rusting away in some basement) had taught educators an important lesson: technology should suit educational needs and not vice versa. Learning from past mistakes, therefore, it is critical that before any technology be adopted, the conditions for a successful language learning environment must first be determined. In order to make a responsible decision about the use of multimedia courses in the classroom, it is critical to differentiate between multimedia technology -- the hardware and software -- and the educational principles underlying use of this technology so that suitability for students, curriculum and presentation style can be determined. It goes without saying that these principles should dictate which educational tools are selected and not vice versa.[89]

To successfully incorporate interactive multimedia and virtual reality into the curriculum, PME 2020 must emphasize their evident benetits. For example:

- Learning is experiential. You try before you fly.

- Saves money and time. You practice on recyclable electrons, not expensive nonreuseable resources. Training examples in and out of the military have already exhibited increased retention, reduced costs, and reduced time.

- Recognizes individual differences. Individuals find details and explanations a mouse-click or virtual eyeblink away, thus leveling the playing field to take into account the variety of backgrounds students bring to the "classroom."

Notes

[1] Gen Merrill A. McPeak, "The Key to Modern Airpower", *Air Force,* September 1993, 46.
[2] "Quest for Quality '94", Air Force Quality Institute, Quality Air Force Symposium, call for papers, to be held 11-14 Oct 1994.
[3] Alvin and Heidi Toffler, *War and Anti-War* (Boston, Mass.: Little, Brown, and Co., 1993), 73-77.
[4] Garrett Culhane, "Mission to Planet Earth", *Wired,* December 1993, 94-97.
[5] CNN, "Future Watch", 27 March 1994.
[6] Culhane, 94.
[7] Ibid., 96
[8] McPeak, 43-46.
[9] Writing in, *Technical Horizons in Education Journal,* Lee Droegemueller, Kansas Commissioner of Education, gives one view of the education world of the next century:

> ... visible transformations in the world of work indicate the future integration of the workplace, home, and school. Responsibilities, functions, and activities that once occurred exclusively within each domain are crossing over into other environments. ... No longer can the school, the office, and the home be separate from one another. These three once-distinct entities are breaking apart, combining and overlapping in new ways.
>
> The major connector of these three entities -- home, school, and work -- is technology ... Thus the direction for planning must be to build the learning community and to focus upon connectivity. This means that the communication systems, networks or infrastructure among the community partners, and how they are connected to the world, become the top priority.

To avoid a similar fate (to businesses which were overwhelmed by technology), schools must use technology for students to learn. Technologically connecting the school with the home and work will make learning relevant and useful. Learning will have no boundaries, as students can connect with others to access information, ideas and experiences from within the community, across the state and around the world.
[10] Lee Droegemueller, "Connecting With the Future Today," *Technical Horizons in Education Journal,* April 1994, 10,
[11] SPACECAST assumptions.
[12] McPeak, 44.
[13] Toffler, 158.
[14] Toffler, 158.
[15] McPeak, 44.
[16] Currently, the military has already started new recruitment strategies in over 50 career fields. These strategies are aimed at recruiting individuals who already possess the basic skills needed for various specialties. These individuals require little if any training in the basics of their career field.[16] The attractiveness of PME 2020 technologies will enhance this strategy. PME 2020 will not only help recruit these targeted individuals, these same technologies will help retain them.
[17] Policy Letter from the Secretary of the Air Force, September 1993, 4.
[18] In a survey referenced in CIO magazine, the importance of various factors in attracting and retaining technology related professionals were rated by those professionals. The opportunity to work with leading-edge equipment was rated as very important by 64 percent of those surveyed, opportunity to work on important projects -- 62 percent, enthusiasm for the mission of the business -- 57 percent, and opportunities for promotion into management received only 36 percent
[19] Joseph P. Shapiro, "Just Fix It", *U.S. News,* 22 February 1993, 50-54.
[20] Philpott, 10.
[21] Shapiro, 53.
[22] McPeak, 44.

[23] Alvin Toffler interview with Peter Schwartz, "Shock Wave (Anti) Warrior", *Wired*, November 1993, 121.
[24] James Kitfield, "Schooled in Warfare", *Government Executive,* October 1991, 22-27.
[25] Tom Peters, *Thriving on Chaos*(Harper Perennial, 1991), 386.
[26] Bruce Sterling, "War in Virtual Hell, *Wired*, Premier Issue 1993,99
[27] Larry Armstrong, Dori Jones, and Alice Cuneo, "The Learning Revolution", *Business Week,* 28 February 1994, 80-85.
[28] Del Wood, "Instructional Technology in the Business Environment", Interactive Multimedia '93 Proceedings, 25-27 August 1993, 52.
[29] Caterpillar used interactive media for language training and saw 50-60 percent savings, and expects to save up to $20 million in US operations alone. Bethlehem Steel uses over 100 interactive courses, including more than 15 as part of their Total Quality Management (TQM) program, and reports 20-40 percent time savings, higher retention, and increased participation in voluntary programs. Ford Motor Credit Company estimates cost savings of 25 percent. Bell South reports one program saved $5 million and 20,000 days of instruction. They also have condensed a five day conventional course into a seven hour interactive course. They report an 80 percent time savings with 40 percent higher retention levels.Ibid., 56.
[30] Ibid., 57.
[31] Kitfield, 24.
[32] Clarence A. Robinson, Jr, "Powerful Nomadic Devices Offer Global Network Access," *Signal* (official publication of AFCEA, March 1994, 23.
[33] News item, "Science and Technology Week," CNN, 2 April 1994.
[34] Jaques Leslie, "Connecting Kids", *Wired*, November 1993, 90.
[35] Jacque Leslie, "Mail Bonding," *Wired,* March 1994, 46.
[36] Ibid., 46.
[37] Gen McPeak, Policy Letter.
[38] For example, the multimedia lessons Air Command and Staff College is integrating into current curriculum may have value at civilian institutions or on the commercial market as well. These or other military-created products could be sold or traded for information or services. As the military develops expertise in authoring in the virtual reality and simulation areas, there no doubt will be opportunities to sell actual or modified products to civilians, or encourage commercial vendors to develop items the military requires, by providing a less risky, guaranteed, military market.
[39] Toffler, *War and Anti-War*, 147.
[40] Current international students have mentioned to Air War College faculty (including one of the authors) after seeing the abilities of the US military, they "are sure glad we don't have to fight you." The open nature of PME 2020 should spread this view on a much greater scale
[41] G. Ronald Christopher and Robert R. Bergseth, "Meeting Air Force Educational Requirements Through Media", Orlando Multimedia '93 Conference Proceedings, 24-26 February 1993, 68-70.
[42] Philpott, 10.
[43] Ibid., 10.
[44] Toffler, *Wired,* 121.
[45] Audrey Merwin, "Videoconferencing Goes to Work," *New Media*, November 1993, 64.
[46] Richard Lipkin, "A Face by Any Other Name", *Science News,* 2 April 1994, 216.
[47] Sterling, 51.
[48] Lipkin, 220.
[49] News Item, "Make Sense of Japanese with Your Own Sensei", *Windows* Magazine, May 1994, 90.
[50] A recent CNN news tidbit featured a computer-generated virtual Mark Twain for rent. This Mark Twain responds to almost any question with a witty response that takes into account all of Twain's writings and biographical notes from people who knew him. He's currently being used primarily for promotional events at shopping malls, but he definitely shows the potential for PME 2020 to introduce historical figures and experts into the classroom.
[51] . Kenneth M. Sheldon, "Micro 2000", *Byte*, April 1991, 132.
[52] 26 years divided by 2 = 13. $2^{13} = 16,384$

[53] Sterling, 98.
[54] 18 months goes into 26 years slightly more than 17 times. Working backwards from 2020 yields $5000 times 2 to the 17th, which equals $655,360,000.
[55] "Special Deliverer", CIO, 1 June 1992, 71.
[56] Bob Metcalfe, "Get Ready for Personalized Newspapers", *InfoWorld*, 5 April 1993, 52.
[57] Sara Hedberg, "VR Art Show at the Guggenheim", *Virtual Reality*, Premier Issue 1994, 73.
[58] News item, *Wired*, April 1994, 38.
[59] A. J. S. Rayl, "Dress Code: The Ultimate PCs Will Be Worn," *Omni*, December 1992, 20.
[60] Bennett Daviss, "Brain Powered," *Discover*, May 1994, 60.
[61] Gareth Branwyn, reviewer, "The Machines Take Over: War in the Age of the Intelligent Machine", *Wired*, Premier Issue 1993, 84.
[62] Donald A. Waterman, *A Guide to Expert Systems*, (Reading, Mass.,: Addison-Wesley, 1986) 289-293.
[63] Advertisement by RPI Advanced Technology Group, in *Virtual Reality*, Premier Issue 1994, 65
[64] Linda Jacobsen, "Homebrew VR", *Wired*, Premier Issue 1993, 84.
[65] Joseph V. Henderson, MD, Dartmouth Medical School, "Virtual Realities as Instructional Technology", Proceedings of S.A.L.T. Interactive Instruction Delivery Conference, 20-22 February 1991, 121-125.
[66] Ibid., 121.
[67] Ibid., 125.
[68] Brian Green, "Technology on Five Fronts", *Air Force* Magazine, September 1992, 62-66.
[69] Ibid., 62-66.
[70] Robin Nelson, "Swept Away by the Digital Age," *Popular Science*, November 1993, 107.
[71] Ibid., 93.
[72] Joe Flower, "Iridium", *Wired*, November 1993, 72.
[73] "Interactive '94" Conference Announcement.
[74] Richard Teach, "What Do We Teach When We Use Games ?", *The Simulation and Gaming Yearbook*, 1993, 112-121.
[75] Del Wood, *Instructional Technology*, 51-58.
[76] The working groups will formulate positions on numerous educational related subjects. Questions such as: 1) what are the true benefits of resident programs versus nonresident ones, 2) when will virtual residency be advanced enough to replace resident programs, and 3) what taxonomy, if any, should replace Bloom's will need to answered when the military begins to incorporate emerging technologies into the PME system.
[77] Col Jack Thorpe, *Business Week*, 5 October 1992, 96-100.
[78] Bennett Daviss, 60.
[79] A.J.S.Rayl, 20.
[80] Air Force Quality Symposium, *Quest for Quality '94*.
[81] Air War College Organizational Plan, 1 June 1994, Initiatives B93AWCTE-05 and B93AWCTE-04.
[82] Candace Golanski, "Looking Back", *Popular Science*, April 1994, 116.
[83] When one of the authors asked an organization about obtaining a copy of a very popular book they had produced, he was informed they did not have enough copies left to freely give them out anymore. Additionally, the organization would have to retype the entire book if they wanted to print more, since neither they nor the printer had kept the floppy disk copy of the text. Ironically, the organizational representative said she thought the disk had been reused to save the cost of buying a new floppy disk. That floppy disk cost 40 cents. Compare that cost to the cost incurred by not keeping it with text intact.
[84] Peters, 554.
[85] John W. Verity, "The Next Step: Reengineering the Classroom", *Business Week*, 28 February 1994, 88.
[86] Armstrong, Jones, Cuneo, 82.
[87] Ibid., 85
[88] *EDUCORP CD-ROM Title Wave Catalog*, Spring 1994.
[89] Maureen Arneaud, "The Potential Impact of Multimedia", Interactive Multimedia '93 Proceedings, 25-27 August 1993, 71.

DEFENSIVE COUNTERSPACE

This paper included in Volume II

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OFFENSIVE COUNTERSPACE: ACHIEVING SPACE SUPREMACY

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FORCE APPLICATION

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PROJECTING INFORMATION POWER IN PEACE AND WAR

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COUNTERFORCE WEATHER CONTROL

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PREPARING FOR PLANETARY DEFENSE:
Detection and Interception of Asteroids on Collision Course with Earth

Subject and Problem Statement

As the Earth revolves around the Sun, it orbits through planetary debris left from the formation of the solar system. Many of the debris objects are asteroids and comets in orbits bringing them close to the Earth and are referred to as Near-Earth-Objects (or NEOs). Of the total NEO population, some portion are in orbits actually intersecting or crossing the orbit of the Earth. The asteroids of this class are known as Earth-Crossing-Asteroids (ECAs). Occasionally, the motion and relative position of the Earth and an ECA in their respective orbits cause them to collide.

The geologic record amply demonstrates that many collisions have occurred in the Earth's past, with over 100 large impact craters still visible around the world. Work over the last decade by the astronomical community validates that impacts will inevitably occur again in its future. In view of these predestined impacts, this paper's purpose is simply stated: Investigate development of a capability to protect our planet from planetary debris (comets, asteroids and large meteoroids) detected in trajectories which will strike the Earth. Such strikes would result in wide-spread devastation or even catastrophic alteration of the global ecosystem.

This paper first investigates the magnitude and frequency of the threat by reviewing the extensive research by the scientific community on this subject over the last several years. Then it looks at some of the technologies and methods for detecting, cataloguing, and tracking planetary debris objects that may be on a collision course with Earth. The focus then shifts to issues associated with mitigation efforts and technology for interception and deflection or destruction of these objects. Finally, it examines the potential cost and benefits of a Department of Defense (DoD) role in an international planetary defense effort. Because of benefits which may be derived, not only to DoD but the world community as a whole, specific recommendations are made on how the DoD might best become actively involved.

During the last fifteen years, research on objects crossing Earth's orbit has increased dramatically. Spurred by the now widely accepted theory that a large asteroid impact caused the extinction of the dinosaurs, the astronomic and geophysics communities have focused more effort in this area. Astronomers, looking skyward with more capable equipment, have been discovering new, potentially Earth-threatening asteroids at an average rate of 10-20 per year. Physicists, enlightened by recent research on the devastating effects even a limited nuclear war would cause to the Earth's ecosystem, have preliminarily investigated the effects on the Earth from an asteroid strike. They estimate that impact by even a relatively small asteroid will release energies equivalent to tens of megatons of TNT. The combined results of these efforts has been a realization that there is a potentially devastating but still largely uncharacterized natural threat to Earth's inhabitants. Thus, the time has come to investigate development of appropriate technologies and strategies for planetary defense.

In fact, recognizing the potential seriousness of such events, the Congress in 1990 mandated that the National Aeronautics and Space Administration (NASA) conduct two workshops to study the issue of NEOs. The first of these workshops, the International NEO Detection Workshop or "Spaceguard Survey" held in several sessions during 1991, defined a program for detecting kilometer-sized or larger NEOs. The second workshop, the NEO Interception Workshop held in January 1992, studied issues in intercepting and deflecting or destroying those NEOs determined to be on a collision course.

Through the end of 1992, 163 NEOs had been detected and catalogued with over 120 of them greater than half a kilometer in rough diameter. But astronomers estimate that ninety-five percent of potentially Earth-threatening objects have not yet been discovered. There are potentially 2,000 to 5,000 asteroids orbiting the sun near the Earth large enough to have devastating consequences on the ecosystem should they collide, and upwards of 10,000 additional objects large enough to inflict considerable damage.

Earth-impacting objects can vary in size from a few centimeters to more than 10 kilometers across. When the object is small, less than 50 meters, the collision is usually mitigated by the Earth's atmosphere, where it burns up or explodes into tiny pieces before it can physically impact the surface. Larger objects strike much less often but of course do much more damage. Sixty-five million years ago, for example, evidence suggests the age of dinosaurs was brought to an abrupt end by the impact of an asteroid that is thought to have been 10 kilometers across. It struck with the force of 100 million

megatons of TNT, leaving an impact crater 185 kilometers across in the Gulf of Mexico off of the Yucatan Peninsula. And in 1908, a 50 meter asteroid is thought to have caused the devastation of a forested area covering over a thousand square kilometers (greater than the size of the Washington, D.C. area) when it exploded in the air above the Tunguska River in Siberia. Had it entered the Earth's atmosphere only three hours later, the Earth's rotation would have effected a 10-15 megaton air burst over Moscow, a force 1000 times greater than the nuclear weapons dropped on Japan in 1945.

Impacts such as the Tunguska incident are thought to occur about once in one hundred years based on the density of impact craters on the Moon. But because of the modest detection research to date, it is not known whether there are any large NEOs having orbits that will definitely intersect the Earth's in the next few decades. Astronomers have been unable to thoroughly catalogue the total population because of limited equipment dedicated to the effort. With an observation network proposed by the Detection Workshop (consisting of six dedicated astronomical telescopes located around the world and data linked to a central survey clearing-house and coordination center), a comprehensive census might still take 20-25 years. Development of this system will benefit from the experience gained by the US Space Command in its space surveillance mission for man-made Earth orbiting satellites, which in turn will benefit from technology developed for detection and tracking of asteroids. After such a system is in operation and has completed the initial catalogue, most large objects headed toward Earth could be detected years or even decades in advance, which is ample time to take action to prevent a collision.

Now that it is recognized that collisions with objects larger than a few hundred meters in diameter not only can threaten humanity on a global scale but have a finite probability of occurring, means for mitigating them seem clearly worth investigation. It should also be recognized that the technology required for a system to mitigate the most likely of impact scenarios is, with a little concerted effort, within humanity's grasp. Such a system could use the latest nuclear explosives, space propulsion, guidance, sensing and targeting technologies coupled with spacecraft technology. These technologies are already related to defense capabilities, but how they are developed for use in space (and what effects they have) will be invaluable experience for defense efforts. Furthermore, a handful of the thousands of nuclear weapons being deactivated under the Strategic Arms Reduction Talks (START) agreement might offer the most expeditious solution to this

problem. Hence, there is much which might be gained from DoD involvement in this effort.

At the same time, the US should not go it alone. The hazards are global, detection efforts will require observation sites throughout the world, and other countries possess heavy lift and other space-related capabilities which could be used. Therefore, any response should involve the international community. This is particularly prudent as mitigation efforts could relate to nuclear capabilities and these intentions will affect arms control treaties. Such an effort is best conducted under the auspices of the United Nations.

The cost for such a system, which might be analogous to buying life insurance, also rightly belongs in the international arena. Gregory H. Canavan, Senior Scientific Advisor for Defense Research at Los Alamos National Laboratory and Johndale Solem, Coordinator for Advanced Concepts at Los Alamos National Laboratory, suggest a possible graduated funding approach. A few million dollars per year could support requisite observation surveys and theoretical study on mitigation efforts. A few tens of millions per year could provide research on interception technologies and procure the dedicated equipment needed to search for large Earth-threatening NEOs. And a hundred million dollars could develop a spacecraft to intercept NEOs for the necessary characterization and composition analyses of NEOs of all sizes.

The conclusion of this paper is that existing US efforts need to be more closely consolidated, coordinated and expanded under national leadership. While there is no reason to live in daily fear, there is a significant danger to our planet from an asteroid impact. Other species are now extinct because they could not take preventive action. Humanity must avoid delusions of invulnerability and acknowledge that as a species we may not have existed long enough to consciously experience such a catastrophic event. But we currently have the technological means for detecting and mitigating the threat and would be remiss if we did not use it.

The Capability and Its Relevance

Most of humanity is oblivious to the prospect of cosmic collisions, but this hazard from space is a subject of deadly concern to the entire population of the planet. Work by several nationally recognized scientists who have been investigating this issue for a number of years, some for decades, has brought an awareness that, to the average citizen of the US, the risk of death may be just as great from an asteroid strike as from an aircraft accident.[1] Those unfamiliar with these studies may find this incredulous when, in fact, there have been no recorded deaths due to asteroid strikes, albeit there have been close calls from small meteorites striking cars and houses.[2] However, the probability is finite, and when it occurs, the resulting disaster is expected to be devastatingly catastrophic. But because we are dealing with events, time scales, and forces well beyond the human experience, the threat is not universally recognized.

The Earth's atmosphere protects us from many dangers in the harshness of planetary space. These dangers range from intense solar radiation to the most common variety of planetary debris, called meteoroids, with diameters measuring only tens of meters or less. As the small meteoroids enter the atmosphere, the heat from friction created by the force of their entry (at 10 to 30 kilometers per second), causes them to completely burn up or explode before they reach the ground. If they burn up, they are then referred to as meteors; if they explode, they are called bolides.

Sometimes, however, even the atmosphere cannot offer total protection. Some meteoroids are of sufficient size and substance that they do not completely burn up before impacting the surface. These remnants are referred to as meteorites and are frequently of an iron-metallic composition. Meteorites are not uncommon and frequently impact in many locations around the world.

What is less commonly known is the force with which these objects can enter the atmosphere and explode or impact the Earth 's surface (figure 1). When a stony meteoroid of 10 meters in diameter hits resistance from the atmosphere greater than its own internal structural integrity, it will explode with a force of about 20 kilotons of TNT.[3] The exact yield of course will depend on the speed of entry and specific composition, but this is greater than the force of the device which destroyed Hiroshima.

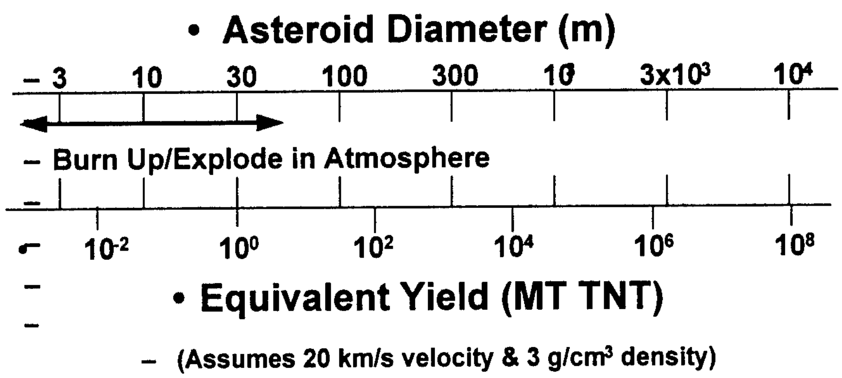

Figure 1: FORCE OF IMPACT
(From Chapman and Morrison)

Many times air-bursts of this magnitude are not witnessed by humans or even detected by earth-based sensing equipment. However, according to data recently released by the Air Force, they are regularly detected by Defense Support Program (DSP) satellites. At least 136 airbursts with a force greater than 1 kiloton of TNT have occurred around the world since 1975,[4] with the latest being detected just this February (with a force equal to 100 tons TNT).[5] But as impressive as this is, keep in mind that these are just the ones that weren't big enough to make it to the ground.

Scientists calculate that it would take a stony object of greater that 50 meters in diameter to survive penetration of the atmosphere.[6] (Planetary debris of this size and larger, up to several hundred kilometers, are generally referred to as asteroids.) Based on calculations derived from surveys of the age and density of impact craters on the Moon, a 50 meter asteroid impact probably occurs at least once a century, and would impact with a force of 10 megatons (Mtons) of TNT[7] (figure 2).

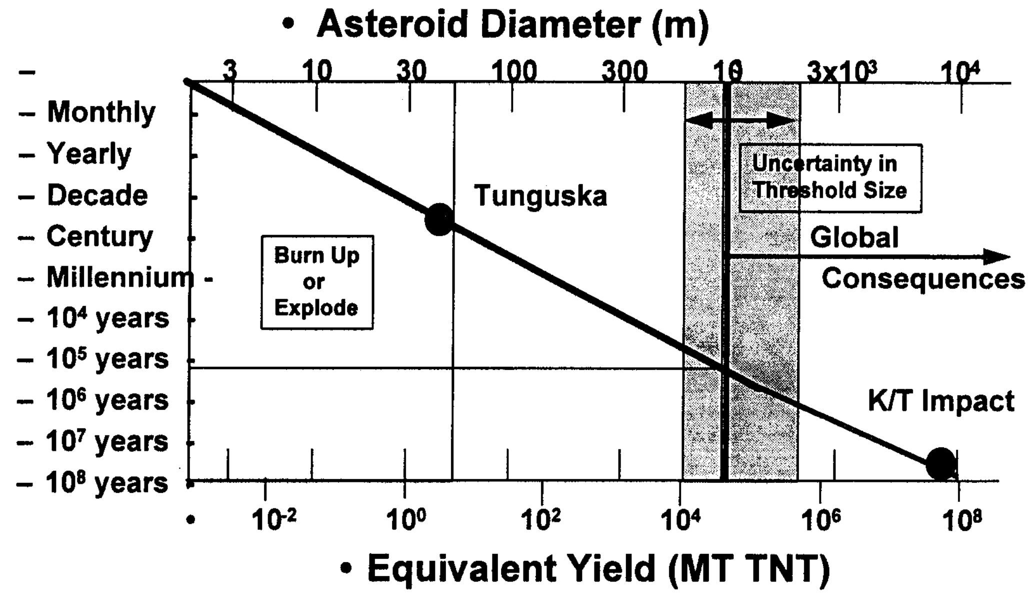

Figure 2: Average Impact Interval versus Size
(From Chapman and Morrison)

An event of this magnitude last occurred on 30 June 1908, in Tunguska, Central Siberia. Although this object did not impact the surface, it is calculated to have exploded with a force of approximately 12 Mtons of TNT at an altitude of 5 to 10 kilometers. It devastated forests over a 1,000 square kilometer area and ignited large fires over thousands of acres near ground zero[8] (figure 3). Had the event occurred just three hours later, a mere microsecond of geologic time, it would have been catastrophic for the citizens of Moscow. There is also evidence that a similar event occurred over New Zealand's South Island about 800 years ago.[9] As populated areas continue to spread across the Earth's surface, the probability of a strike in a population center increases accordingly.

But a 50 meter asteroid impact would only produce relatively localized effects. Meteor Crater near Winslow, Arizona, is an evident example of such a comparatively small impact. Larger impacts have caused more damage, as is evident from the Moon, although it has taken satellite imagery, such as from LANDSAT, to help realize the extent here on Earth. Using satellite photos, geologists have begun detecting more and more features on the Earth's surface that are actually remnants of impact sites. Some are quite

large, such as the Manicouagan Crater in Canada at over 65 kilometers in diameter. Almost all have been partially obscured due to centuries of exposure to the effects of weathering, making them difficult to detect while on the ground.

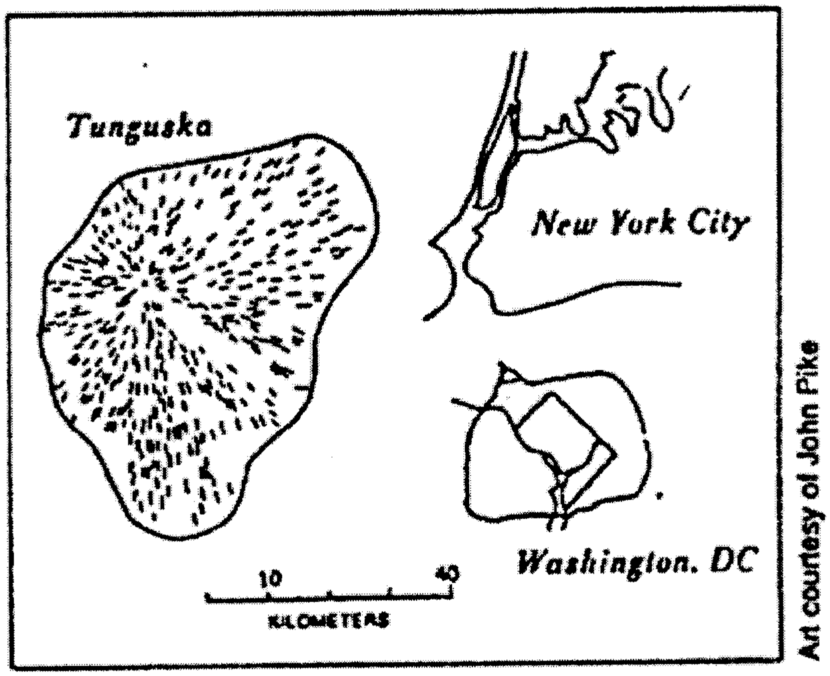

Figure 3. A perspective of the area of devastation caused by the Tunguska event compared to current urban areas. If such an event were to occur over an urban area, hundreds of thousands would be killed, and damage would be measured in hundreds of billions of dollars.[10]

There is also mounting evidence that an impact by a large asteroid (or asteroids) brought an end to the dinosaurs. A theory first advanced by the father-son physicist-geologist team of Luis and Walter Alvarez in 1980, it is now widely accepted, by geologists and paleontologists alike, that an impact by one or more relatively large asteroids occurred approximately 65 million years ago. This cataclysmic event is believed to have wiped out the dinosaurs and many other species on the Earth as well from the immediate and more long term effects of the impact(s).[11] Scientists now believe the most likely site of at least one large impact from that time is in the Gulf of Mexico, off the northern coast of the Yucatan Peninsula. Readily visible evidence of the impact has long since been obscured by the Earth's dynamic surface changes but the subsurface rock still bears wounds from this catastrophic event.[12]

Estimated to be greater than 10 kilometers in diameter, the suspected asteroid would have struck with a force of about 100,000,000 Mtons of TNT, or 10,000 times the total of all the world's current nuclear arsenal.[13] Not only did this impact create a large crater, but it would also have thrown trillions of tons of material into the Earth's atmosphere and started a global firestorm which would have added more smoke and soot to the layers of dust already in the stratosphere. Then a global winter resulting from blockage of the Sun's heat reaching the surface might have lasted for more than a decade, accounting for the extinction of at least half of the different species of life on the Earth at that time.[14] The settling of this dust to the surface created what geologists refer to as the "Cretaceous/Tertiary (K/T) Boundary," which is a physical demarcation in Earth's geologic record (i.e., rock layers) between these two ages and led to the Alvarez theory. Furthermore, paleontologists have discovered several other points of mass extinction (figure 4) in the geologic record with the speculation being they may have been caused by the same type of event.[15]

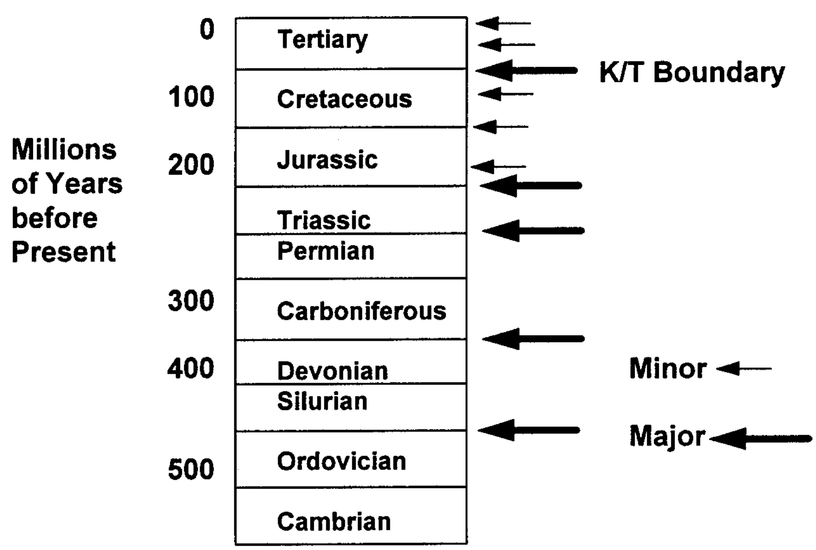

Figure 4: Mass Extinctions in Geologic Record
(From Chapman and Morrison)

But it doesn't take a "planet buster" of 10 kilometers diameter to wreak global havoc. Scientists estimate that the effect from an impact by an asteroid even as small as 0.5 km could cause climate changes sufficient to dramatically reduce crop yields for one or more years due to killing frosts in the mid-latitudes in the middle of summer. Impacts

by objects 1 to 2 km in size could therefore cause a significant increase in the death toll due to mass starvation by a significant portion of the world's population as few countries store as much as even one year's required amount of food. The death toll from direct impact effects, blast and firestorm, as well as the climatic effects could approach 25 percent of the world's human population (figure 5).[16] Even though it may be a rare event, happening only every few hundred thousand years, the average annual fatalities from such an event could still exceed most natural disaster more familiar to us (figure 6).

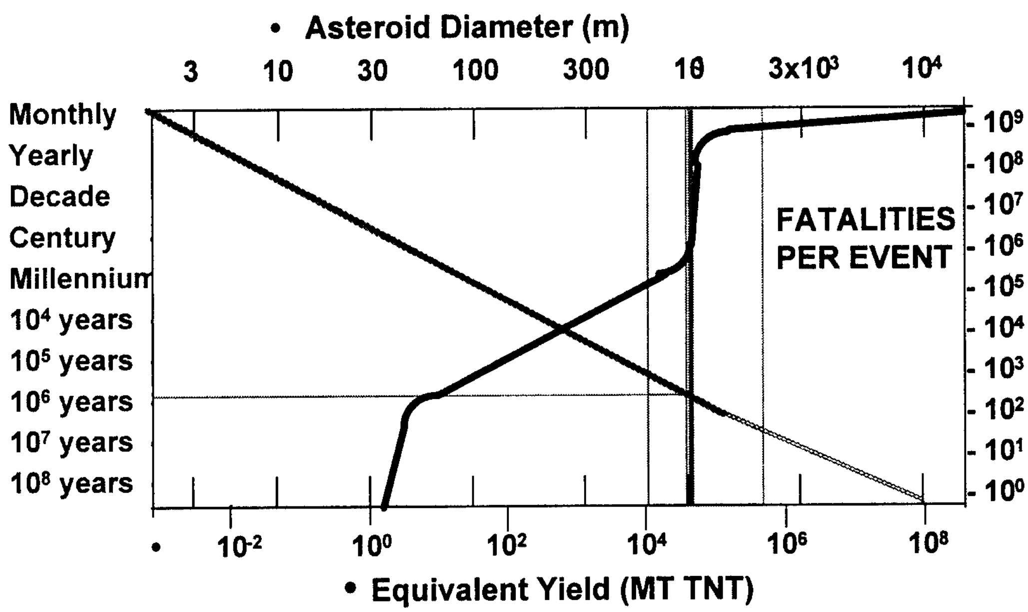

Figure 5: Fatalities per Impact Event
(From Chapman and Morrison)

This would be a natural disaster totally outside the human realm of comprehension and leads many people to be skeptical that anything like this could ever happen despite the results of many recent studies by the scientists. It is similar to an individual's egotism that a fatal accident will never happen to them, only on a much grander, entire species-level scale. Like the danger of a large earthquake in southern California, people do not comprehend the risks involved as having any relation to their daily lives. But the threat discussed here gives new definition to "The Big One."

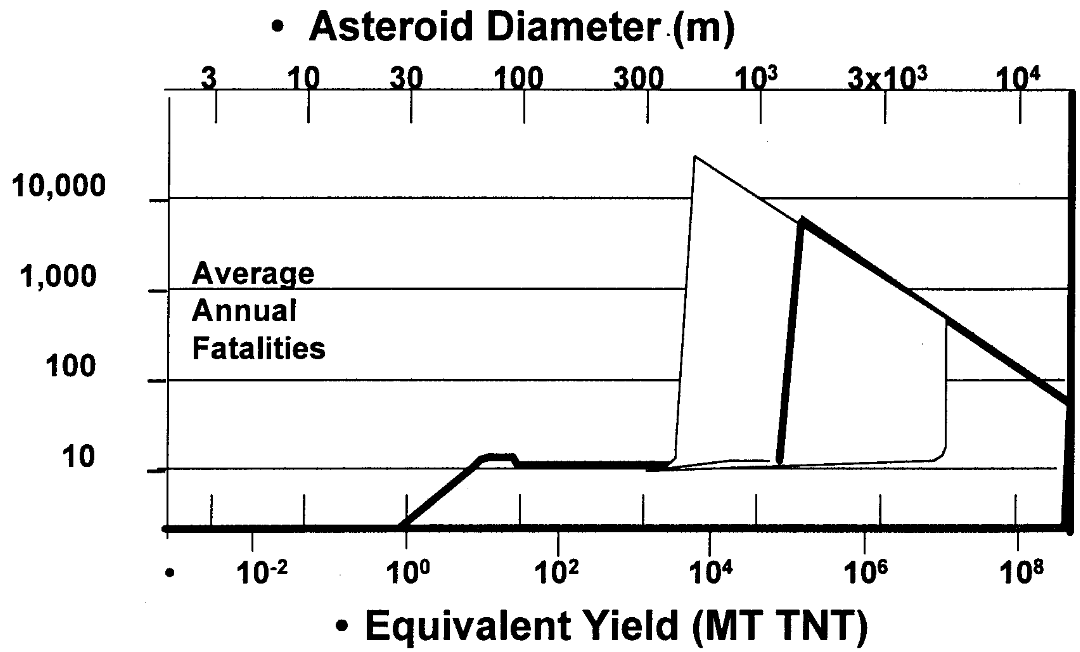

Figure 6: Average Annual Fatalities vs Impact Event
(From Chapman and Morrison)

As devils advocates," some might argue that all asteroids of this size have already been swept clear by the planets over the millennium. However, in the last two decades, astronomers have catalogued over 120 asteroids of 0.5 km or larger in orbits around the Sun that also cross the Earth's orbital path.[17] (See tables on ECAs in Attachment 1.) The work to detect the NEOs has been going on for a couple of decades and new techniques and technology have increased the rate in which they are being discovered. On average, two or three NEOs of a few tens of meters or more in size are currently being found every month.

As timely proof that cosmic impact events do still occur, a comet named Shoemaker-Levy 9 is predicted to impact the planet Jupiter in late July of this year.[18] (figure 7). This is certainly not an every day occurrence and this is the first time astronomers have known about such a spectacular event in advance, providing a chance to observe it happen. This will be an event of unprecedented interest to all space scientists and astronomers, as it should be for all planetary inhabitants, as a demonstration of what cataclysms can occur in the natural environment.

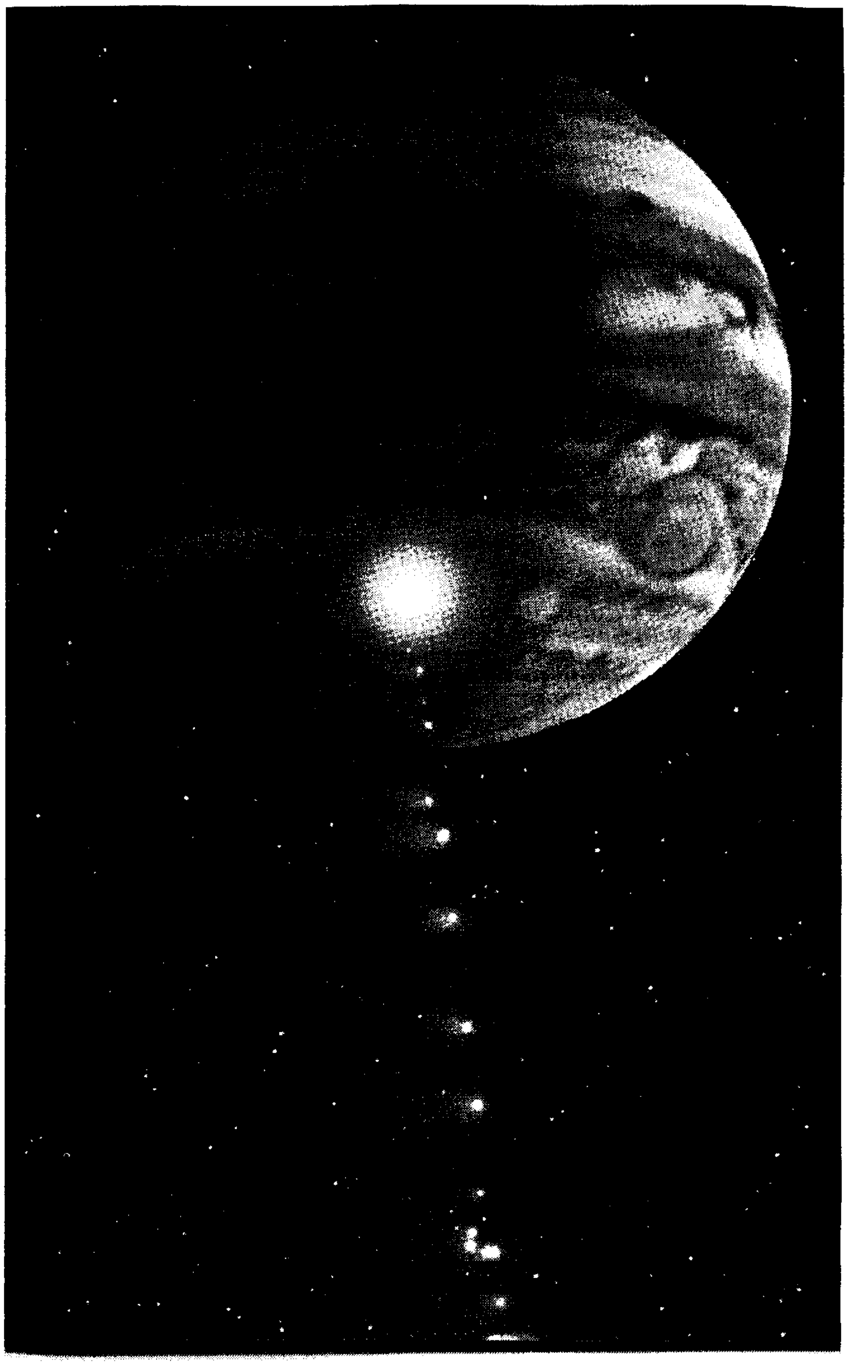

Figure 7. Depiction of the first components of Shoemaker-Levy 9 striking the surface of Jupiter. The comet was broken up by an earlier close encounter with the gas giant in July 1992 and there are 22 pieces, at last count, strung out over almost a million kilometers. The components, the smallest visible from Earth estimated to be at least 1 kilometer in diameter, are predicted to impact approximately every six hours between 16 and 22 July 1994. Visible remnants of these impacts might be features similar to Jupiter's current Giant Red Spot, shown to the right of the first impact in this illustration.[19]

Astronomers believe they may have found only about 5 percent of the total number of asteroids greater than 0.5 km in size. Based on estimated asteroid population densities, astronomers believe there are well over 2,000 such asteroids in Earth crossing orbits. However, at the current rate of progress, it will take over 100 years to ensure they have catalogued at least 90 percent of them.[20] A proposed global detection system might reduce this to 25 years, but even so, new members of this ominous population are continuously being created by the interaction of the planetary gravitation fields on the main asteroid belt between Mars and Jupiter and the comets entering the inner solar system from deep space.[21]

So how does all this boil down to the rather significant risk of death by asteroid mentioned earlier? In round numbers, scientists estimate there will be an impact on the Earth of an asteroid large enough to have global consequences every 500,000 years. So the probability of a strike in any one year is 1 in 500,000 assuming they are completely at random. Since 25 percent of the world's population could die as a consequence, the risk of death for any one individual, if such a strike occurred, will be one in four as a worldwide average. Therefore, the risk of death in any one year for an individual is 1 in 2,000,000. Over a seventy-five year lifetime the risk will then be about 1 in 25,000. This is within the ball park of the before mentioned risk of death to a US citizen in an aircraft accident or any number of other yearly accidents or natural disasters such as hurricanes, earthquakes and floods (table 1), all for which this nation spends tens of millions of dollars each year to both warn people of their approach or to mitigate their effects.[22]

The authors wish to make clear they are not crying, "The Sky is Falling!" and are not advocating a crash program costing billions of dollars to build an asteroid deflector. No specific asteroid projected to impact the Earth has yet been identified and many years may pass (hopefully) before one is. However, the probability is finite. Indeed, one day it will be exactly equal to one. Even if one does find the risks of death due to an asteroid outlined above difficult to accept, it is known that the Earth has been impacted by large objects in the past and that someday the planet will be faced with the prospect of another such catastrophe. Currently, astronomers have no idea when that day will come, hence a modest but prudent ECA detection program is warranted. A few million dollars judiciously spent may buy mankind substantial peace of mind. However, it may also alert us to the prospect that our day of reckoning is closer at hand than currently realized.

Table 1: Relative Probability of Death by Asteroid Impact (From Chapman and Morrison)

Chances of Dying from Selected Causes in the USA

Motor Vehicle Accident	1 in 100
Murder	1 in 300
Fire	1 in 800
Firearms Accident	1 in 2,500
Electrocution	1 in 5,000
Passenger Aircraft Accident	1 in 20,000
ASTEROID IMPACT	**1 in 25,000**
Flood	1 in 30,000
Tornado	1 in 60,000
Venomous Bite or Sting	1 in 100,000
Fireworks Accident	1 in 1 million
Food poisoning	1 in 3 million
Drinking Water with EPA limit of TCE	1 in 10 million

Therefore, it is also prudent that some effort, mainly mental, be spent to examine what capabilities we currently have versus what capabilities we may need to counter such a threat. Once these are identified, contingency plans can then be formulated to have on the shelf, if the need arises. Also, a coherent path could be developed to get capabilities to a more viable state by encouraging the development of applicable technologies which will not only help to deal with this problem, but would also offer many benefits in the exploitation of space and spin-offs for commercial applications.

This brings the discussion to why the DoD should take an active interest in this issue. Of course should such a disaster actually occur, at least four compelling reasons come immediately to mind.

1. The resulting need for humanitarian relief. The DoD will certainly be involved in any humanitarian relief effort after such a disaster. Humanitarian relief efforts have become a significant mission for our forces, with many examples during the last few years, not only in the US with relief efforts for victims of Hurricane Andrew in 1992 and the Midwest Floods in 1993, but also wherever it might be needed in the world. But

these examples will be relatively minor efforts compared to what might be needed in response to even a relatively small impactor if it occurred in a populated area. This might require a concerted effort from many nations and place a severe strain on the resources of the international community even if everyone was cooperative.

2. The possible destabilization of the international community. A natural disaster of this magnitude could put tremendous pressure on the nations involved, both friend and foe, destabilizing not only their economic but social fabric. Indeed, such a calamity will affect the entire world community. Governments have lost stability to lesser disasters when they found their resources lacking to adequately respond to the needs of its victims. Many times it has only been the infusion of external aid that has prevented more severe outcomes. What will be the result when a significant portion, such as 25 percent, of the world's population is in need of aid, particularly when it is not known how long the effects may last?

3. The possible threat to national security. Given such an event, the effects could very well threaten the national security of the US, even if it were not physically impacted. How will the international community deal with scenarios in which a significant portion the world has almost literally been turned upside down? The devastating effects to governmental and societal structure are equivalent to those thought of when talking about a post-global-nuclear war holocaust, lacking only (maybe) the lethal radiation effects.

4. The anticipated nation-wide call for action. Were an impactor to be detected in advance, the nation and perhaps the entire planet will quite naturally look to the DoD for the fortitude, technical expertise and leadership, not to mention the required force in the form of nuclear devices, to counter such a threat to its citizen's lives and well being. Other organizations and agencies will certainly be involved, including the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), the Federal Emergency Management Agency (FEMA), and the Office of Foreign Disaster Assistance. There will also most likely be an international effort. However, few organizations other than the US DoD have the experience and wherewithal to even attempt such an effort. The Russian military and space infrastructure is probably the only other viable capability equal to the task, but such a project could indeed take a consolidated effort and probably rightfully should, given the common fate. Suffice it to say that the DoD will form the core around which the rest could organize.

All these potential effects from an asteroid impact are currently within the DoD charter of responsibilities, as contained in the National Military Strategy and Joint Doctrine for Contingency Operations (Joint Pub 3-00.1), for any number of more commonly occurring events. Just because it may only happen once in 300,000 years doesn't absolve the current defense team of at least a moral responsibility if it does occur on their watch, particularly if they had the capability to prevent or at least mitigate it. Perhaps for the first time in not only human history, but the battered history of the planet, the inhabitants of Earth are on the verge of having such capability.

There are no known techniques for preventing many natural disasters such as earthquakes, hurricanes and tornadoes. Some cannot even be detected in time to give adequate warning to the affected population. Such is not the case with asteroids. Mankind certainly has the technology that, with a relatively modest investment, will provide warning of an impending catastrophe maybe years and perhaps decades in advance. In most cases more than enough warning time could be given to allow evacuation of affected areas for the smaller objects once an adequate detection system is in operation. Humans also possess the technical understanding of the forces required (orbital mechanics and nuclear explosives) to prevent such disasters, at least up to a 10 km size asteroid, given enough warning time.

Potential Technologies to Counter the Threat

Work is needed in two broad areas: capabilities to detect and characterize the potential threat and capabilities to mitigate it once a specific threat is identified.

A threat is defined as a planetary debris object (asteroid or comet) of sufficient size and composition to do significant harm to Earth's inhabitants either by direct impact effects or damage to the ecosystem should it strike the planets surface or explode in its atmosphere. The analysis examined earlier showed this to be, at most, all objects greater than 50 meters in size because these are the ones with the potential of surviving their entry into Earth's atmosphere. However, one could argue that objects smaller than 500 meters should not be of concern since their effects would be relatively localized and most probably, at least for another century or so, would fall in unpopulated areas. This fortunately was the case for the Tunguska event (which was not even an impact), but had it occurred over a populated area the loss of life would have been consequential. As the

human population spreads, the probability for great loss of life due to any sizable impact anywhere on land goes up.

Even ocean impacts of these smaller objects are of some concern because of the potential for tsunamis being created by even an object as small as 100 meters.[23] A fifty foot ocean wave could do significant damage to surrounding coastal areas, actually increasing the destructive potential above that from a same sized object's land impact. This is a hypothesized phenomena not yet well understood. Also, some might even consider the loss of flora and fauna in even unpopulated areas to be of significant enough concern to be worth some amount of effort. So drawing the line somewhere above the 50 meter size invites some debate.

However, the remainder of this paper concentrates on objects greater than 0.5 km and up to about 10 kms, with the understanding that anything larger is an exceedingly rare event, even by our standards. Capabilities against this chosen class, defined as smaller than (<) 10 km but larger than (>) 0.5 km, will also give significant capability against anything smaller, with the notable exception being distant detection of the object.

Surveillance - Detection, Tracking and Characterization

Scientists who have worked with this issue for a number of years have put much thought into the surveillance issue. Some prototyping of potential systems has already been done, a notable example being the Spacewatch System at Kitt Peak, Arizona, organized by Dr. Tom Gehrels of the University of Arizona who has worked on this issue for over three decades. There are already some specific ideas and programs which could be quickly initiated using dedicated ground based sensor networks based on current technology. Unfortunately, lack of any significant funding has kept even a modest program from being started. Until this year, the Spacewatch System was run on a shoestring through private donations.

In the report of the NASA study commissioned by the US Congress, resulting in three Near-Earth-Object Detection Workshop sessions held during 1991, the scientists propose an internationally supported detection system they call the "Spaceguard Survey Network," after a system conjectured by Arthur C. Clarke in his science fiction novel *Rendezvous with Rama*. This system will provide detection of objects as small as 1 km diameter within a suitably large volume of space using a network of six globally

dispersed 2.5 meter aperture, f/2 prime focus reflecting telescopes, each with four 2048X2048 pixel charge-coupled device (CCD) detectors in the focal plane. Automated signal processing and detection computer systems will recognize asteroids and comets from their motion against the background of stars. All technology for this system has already been demonstrated in the prototype at Kitt Peak. Acquisition costs for such a system could be as low as $50M and the annual operations and maintenance costs will be in the $10M range. This system could be in operation in less than 5 years after funding is made available.[24]

This system sounds remarkably like the Ground-based Electro-Optical Deep Space Surveillance System, or GEODSSS, albeit with smaller one meter telescopes and CCDs, but built at four sites a decade ago and currently operated by the Air Force to track man-made geosynchronous satellites. However, this Space Command surveillance asset does not do wide area searches needed for asteroid detection, but rather searches for man-made objects based on their predicted position and rejects the detection of any object which moves as fast as an asteroid, providing it were close enough to be seen. In a way, GEODSSS does the converse of what Spaceguard sites will need to do. However, it could probably be upgraded to do asteroid detection if it weren't already heavily tasked with its current mission.

But, there are many parallel techniques between what the Spaceguard Network will be required to do and what is currently done by US Space Command's network for space surveillance of man-made objects. The Spaceguard Report also speaks to the need for a "survey clearinghouse and coordination center" to catalogue newly discovered objects, coordinate observations by other sites to verify existence of each object and collection of additional sightings to determine their orbits. This center will also project the orbit of each object, both for recovery (sighting of the object on the next orbital pass) and to determine if it poses a threat to Earth. All this is currently done for asteroids and comets by the International Astronomical Union's Central Bureau for Astronomical Telegrams and Minor Planet Center in Cambridge, Massachusetts, but at a rate far less than will be needed for the Spaceguard Network. NASA has plans to establish such a center at the Jet Propulsion Laboratory in Pasadena, California. This activity could benefit greatly from the experience and automation used for similar tasks done for man-made objects in Earth orbit by Space Command's Space Surveillance Center (SSC) at Cheyenne Mountain AFB, Colorado. This is not to say that this existing network could

easily take on this additional task (it couldn't), but it is to say that Space Command has significant experience in a closely related area which could be applied to the problem.

However, Space Command's current space surveillance mission could also benefit from systems developed for asteroid surveillance. Optical systems developed to detect and track these relatively dim objects (down to 22nd magnitude) might also find application against the tracking problem presented by man-made orbital debris. Precise tracking of asteroids can also be greatly enhanced with augmentation by powerful deep space radar systems. Currently there are only two such system available (Arecibo, Puerto Rico, and Goldstone, California) and even their performance is limited in relation to this task. Research and development on more capable radar systems will probably be of benefit to the traditional space surveillance mission, not to mention other defense related areas. Work on sensors, both active and passive (microwave, multi-spectral and hyper-spectral) could also be of mutual benefit. In the software and modeling arena, both missions will benefit from development of more precise and comprehensive, as well as rapid, orbit prediction models. This might also lead into further use of parallel processing techniques for space surveillance that are just starting to be investigated. The bottom line is that great potential can be seen for cross flow of technology, equipment and techniques between these two space surveillance missions which in itself will warrant interest by the DoD.

So far, only ground based technologies have been addressed. It is always advantageous when dealing with dim celestial objects to get up above the atmosphere to eliminate its interference with the object's signature and the diurnal constraints imposed by the Earth's rotation. The asteroid detection and tracking mission by itself may not warrant space based capabilities, but coupled with other more traditional Air Force missions a mutual benefit will be gained. More distant, and therefore earlier, detection of both asteroids and comets will be possible from space based systems. It will also give greater capability against a class of asteroids, called the Atens, which are defined by their orbits about the Sun being inside of Earth's but reaching out far enough to cross the Earth's orbit (orbit diagrams, figures 8-11). Because ground based systems will almost always be looking toward the Sun to see objects in this class, they are difficult for ground based observatories to detect. Although less than 15 objects in this class have so far been discovered, it is speculated this class may be at least as common as the Apollo class, asteroids in orbits more similar to Earth's and the class to which the majority of known ECAs (over 100) belong. Astronomers point out that Mercury, the planet closest to the

Sun, has more craters than any other object in the solar system.[25] Therefore a space based surveillance system, perhaps even Moon based or at a stable Earth-Sun Lagrangian point (L2 or L5), would have distinct advantages in covering certain classes of objects.

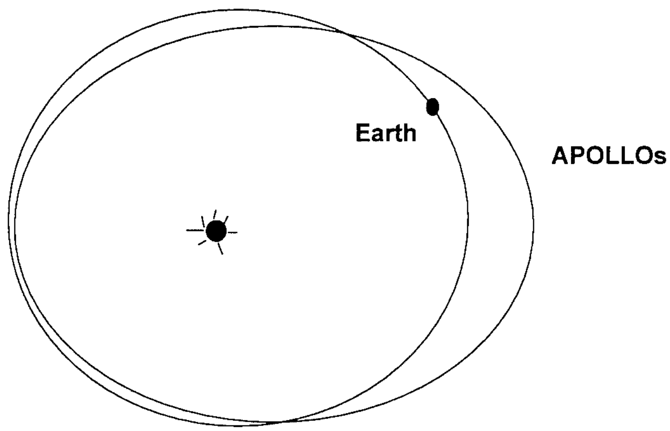

Figure 8: Orbits of Apollo Asteroids

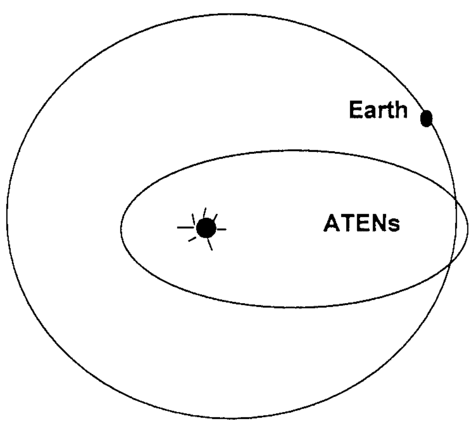

Figure 9: Orbits of Aten Asteroids

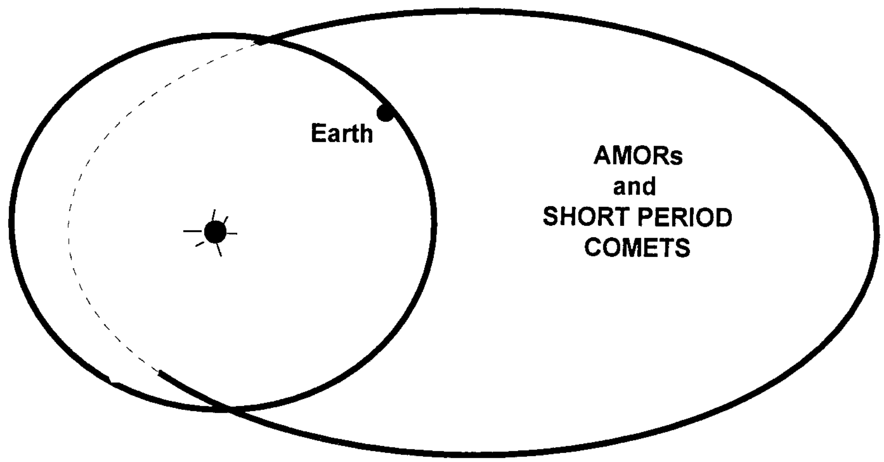

Figure 10: Orbits of Amor Asteroids and Short Period Comets

Note: The dotted portion of the orbital path represents motion of the asteroid or comet below the plane of the Earth's orbit. This is due to the high inclination of the object's orbit which is common for these types of objects.

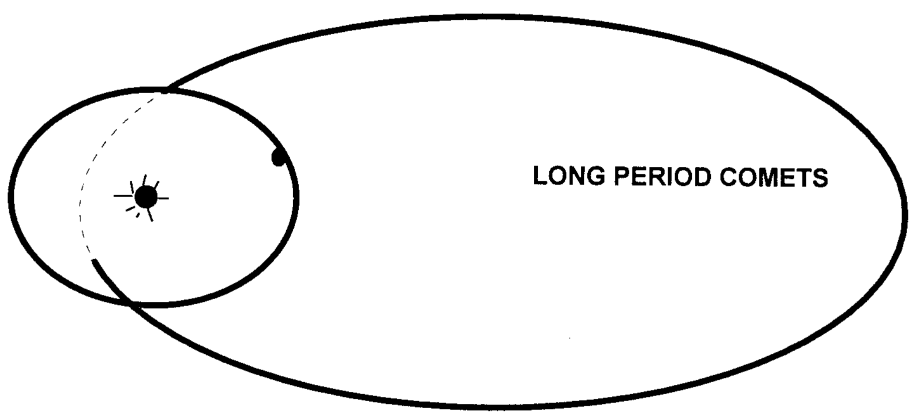

Figure 11: Orbits of Long Period Comets

Finally, discussion of the surveillance mission, ends with characterization of the asteroids and comets. Although their existence has been known for almost two hundred years, still little is known about their composition, or even if it is common for them to be the typical solid, large rock-like body usually envisioned. There is some speculation that many of them may actually be more like orbiting rubble piles. Little more is known about comets although they are typically thought of as dirty snowballs.

Many things can certainly be learned from a concerted remote sensing program. But before we can have full confidence about what effects certain mitigation techniques might have, a closer-in survey will need to be done, especially given enough warning about a specifically identified threat to impact. Hence, asteroid and comet rendezvous missions are of great importance to the surveillance of this potential threat to ensure as much as possible is learned about these possible threats. Because of the space community's interest, close approaches to main-belt asteroids were added to the Galileo Jupiter mission. It passed within 1600 km of the asteroid Gaspra in October 1991, and to within 3200 km of the asteroid Ida in August of 1992, discovering it has as smaller asteroid moon orbiting it. NASA Space Sciences Office is also planning a Near Earth Asteroid Rendezvous (NEAR) spacecraft to co-orbit for at least one year with an Apollo asteroid later this decade. These are examples of the kind of missions that can be done with current technology. The currently ongoing Ballistic Missile Defense Office NASA sponsored Clementine mission to the Moon, with a planned close approach to the asteroid Geographos to test SDI developed sensors, is an example of the kind of mission with mutual benefits which can be conducted.[26] The recent attitude control malfunction with Clementine will probably lead to the cancellation of this phase of the mission (as of this writing, 25 May 94). However, the mission as planned still stands as an example of the kinds of projects which can be done. History may well look back on the Clementine mission as the DoDs first foray into this new mission area.

Threat Mitigation

Mitigation of Earth-threatening asteroids and comets, to include both deflection and fragmentation options, has received substantial attention over the last three years. In particular, the NASA-sponsored Near-Earth-Object Interception Workshop investigated the subject in-depth and made this conclusion: "... chemical or nuclear rockets with nuclear explosives are the only present or near-term technology options available that have significant probability of success without significant research and development

activities."[27] More succinctly, the Chairman of the workshop indicated to Congress that "... technologies currently exist that could be integrated into systems capable of protecting the earth from most any NEO impacts."[28] In short, technology options exist, if pursued, which can mitigate the asteroid and comet threat.

As both background and support for the conclusions above, this section addresses mitigation strategy and intercept scenarios, reviews the NEO threat in light of these intercept scenarios, and then presents a selection of mitigation options. Finally, this section addresses the sensitive implications of using nuclear explosives in an earth-defending role.[29]

Mitigation Strategy

The fatality curve introduced in a previous section (figure 5) serves as a guide to both optimize and prioritize mitigation systems. This curve rises sharply and peaks with asteroids one-to-two kilometers in diameter--the threshold size for global effect as previously discussed--and then decreases inversely with asteroid size. Or, from a different perspective, as asteroid size increases, the effects of impact shift from being regional to global in nature. At the same time the probability of impact goes down. The combination of these two characteristics shape the curve and create the peak. The point is this: asteroids and comets correlating to the peak in average annual fatalities should be the first focus of any mitigation development efforts; in short, threshold-sized objects. Those beyond threshold size are second in priority while those smaller are, of course, third. Intuitively, options which dispatch large asteroids should also accommodate the small ones, but this may lead to a situation analogue to trying to kill a fly with a hammer. There may be less-complex, less-costly, and thus more appropriate options for handling small NEOs, and these should be considered as well. Now, before considering potential options, it is helpful to consider intercept scenarios and re-consider the threat.

Intercept Scenarios

There are two intercept scenarios, distant and close-in (table 2).[30] Distant intercept, which implies distance in both space (interception at the Sun, i.e., NEO perihelion) and time (interception at two or more orbits prior to predicted final approach), is the scenario of choice. This is desired since relatively small deflections suffice and, accordingly, lends to using the full range of propulsion and deflection technology options

available. Importantly, it allows for a "deflect-look-deflect" style of operation which is prudently conservative in nature. Finally, if when attempting deflection fragmentation occurs, the resulting debris will have time to disperse before reaching Earth. By way of calibration, deflection velocities for the distant intercept scenario are on the order of centimeters per second.[31,32]

Table # 2: Intercept Scenarios [33]

1) Distant Intercept ... *the simpler case*

- Small deflections suffice
- Allows full range of options
- Opportunity for deflect-look-deflect

2) Close-In Intercept ... *the harder case*

- Large deflections
- Limited to high energy options
- One or two shots

The close-in scenario is the more challenging case and involves interception of an object on final orbital approach. This will likely occur a few tenths of an AU from Earth (AU, Astronomical Unit = 150 million kilometers) and require deflections on the order of a thousand times larger than the distant intercept case.[34] The need for larger deflections will limit propulsion and deflection technologies to those providing high energy and, accordingly, have increased potential for inadvertent fragmentation. Finally, time may only allow for one or two attempts at deflection. It is now helpful to review the threat in light of these two intercept scenarios.

Threat Categories

Following the lead of the Interception Workshop, there are four threat categories as identified in Table 3. The first two categories are clear candidates for distant intercept while the second two will likely require close-in deflection. In each category, warning time is the obvious key figure of merit.

The first category includes objects whose orbits can be well-determined, specifically the ECAs. Once discovered and catalogued, subsequent optical measurements of these objects in combination with radar tracking can yield orbital predictions with tight position errors (i.e., on the order of one Earth's radius). These predictions can be made well into the future, giving decades of warning time.

Table # 3: NEO Threat Categories[35]

1) Well Defined Orbits
   - Earth-Crossing Asteroids (ECAs)
   - Warning Time: Decades

2) Uncertain Orbits
   - Newly Discovered ECAs; Short-Period Comets
   - Warning Time: Years

3) Immediate Threat
   - Long-Period Comets; Small ECAs
   - Warning Time: 1-12 Months

4) No Warning
   - Long-Period Comets; Unknown ECAs
   - Warning Time: 0-30 Days

The second category also includes ECAs, but newly discovered ones for which the orbits have not been well-determined due to limited tracking opportunities. Some asteroids may also display chaotic variations in orbital eccentricity which further confound prediction (figure 12).[36] In the words of Chapman and Morrison: "an asteroid can orbit for hundreds of thousands of years in a perfectly regular, sensible way, and then quite suddenly its orbit can change chaotically into a comet like, elongated path that comes near the Earth."[37] This category also includes short-period comets (period < 20 years) which, due to outgassing while near the sun, have non-gravitational components to their orbits which make them hard to predict. This outgassing creates their characteristic tail, but also creates the coma surrounding, and thus obscuring, the comet's solid body. This, too, contributes error. Orbital uncertainties for both of these objects, ECAs and short-period comets, limit warning times to years.

The third category includes long-period comets (period > 20 years) and newly discovered ECAs. The comets can come from any inclination and can be a first time visitor, making their early detection difficult but critical. Earliest feasible discovery of a long-period comet on "final approach" will yield at best several months warning time. Newly discovered ECAs, perhaps succumbing to Chaos Theory, or ones simply missed during the survey, may also yield limited warning times.

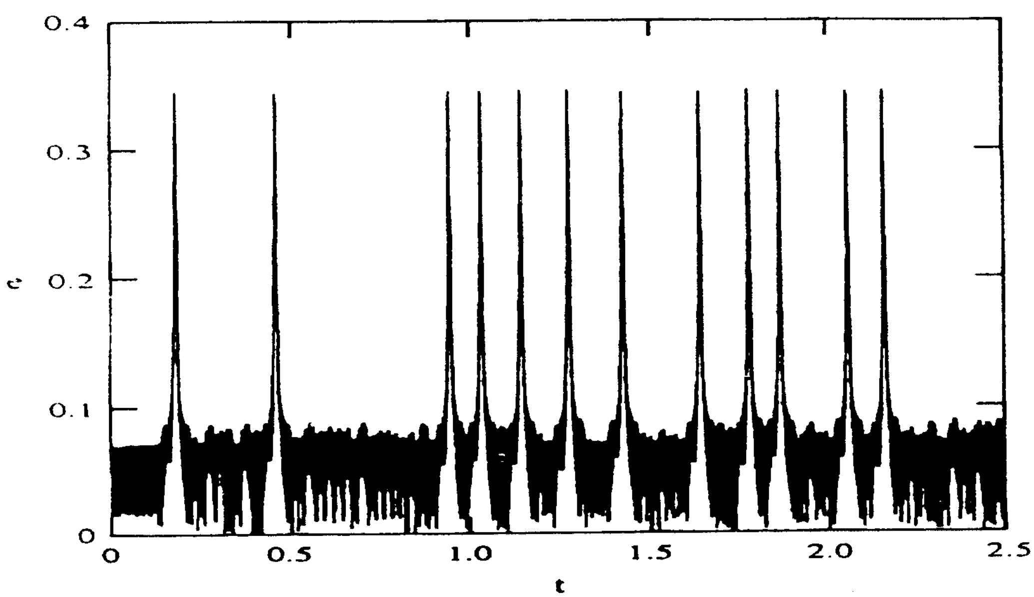

Figure 12: "Chaotic variations in the eccentricity of an asteroid orbit over 2.5 million years, as calculated by Jack Wisdom of MIT. Normally the orbit is quite circular, but at irregular intervals it becomes very elongated (eccentricity greater than 0.3)."[38]

The final category is the "horror scenario" and involves objects arriving with little or no warning. Ironically, because of the lack of detection capability, this scenario is the most likely case. As a result of this lack of warning, mankind will be limited to evacuating expected impact sites. There will not be time for defensive measures.[39] As survey efforts continue though, this category will decrease in scope while the others grow larger and we will have more time to employ appropriate defensive action. Having defined intercept scenarios and the threat, we now consider mitigation options.

Mitigation Options

To first order, current technologies can mitigate threatening asteroids and comets. There are basically two technology areas to consider: those related to propulsion and those related to deflection/fragmentation (table 4). Given the notional rigor of this paper, all the technologies discussed below are assumed applicable to both distant and close-in intercepts. System sizing and sensitivity analyses are beyond the scope of this effort.

Table #4: Propulsion and Deflection Technology Options [40]

1) Propulsion	
- Chemical	... Current Technology
- Nuclear, Mass Drivers	... Next Two Decades
- Hypervelocity, Antimatter	... Several Decades
2) Deflection/Fragmentation	
- Nuclear, Kinetic Energy	... Current Technology
- Lasers, Ultra-High Kinetic Energy	... Next Two Decades
- Antimatter, *in situ* Mass Drivers, Solar Sails, Asteroid Eaters	... Several Decades

For propulsion design, a system with high specific impulse is desired to maximize effectiveness. This property will give a rocket high enroute velocity and thus increase the chances for a distant intercept. It will also give high terminal velocities, and hence kinetic energy, which can broaden deflection/fragmentation options. And as a function of system design, high specific impulse could allow for relatively large payloads. Nuclear propulsion offers the best near-term advance in specific impulse over current technology, specifically by a factor of two or three over chemical propulsion designs.[41] Both the US and Russia have developed nuclear propulsion systems, but to the best of the authors' knowledge, none has yet been tested on-orbit. Recent efforts have been retarded or canceled given that no current or near term DoD lift requirements mandate nuclear capabilities.[42] Planetary defense could mandate such a design. Metastable fuels also hold the promise of increased specific impulse in the near future with metastable HE_4 offering a six times improvement over chemical designs.[43] Other propulsion options, clever but highly speculative and not likely to be available by 2020, include mass driver reaction engines located *in situ,* hypervelocity systems employing nuclear explosions to

impart momentum, and antimatter devices.[44] But again, and in summary, it appears that chemical and nuclear propulsion systems now in development offer the best options for planetary defense.

Deflection/fragmentation options constitute the second technology area. Kinetic energy projectiles and nuclear devices offer current solutions. By way of calibration, a 200 kg projectile with 12 km/s closing speed (within the capability of chemical systems) could successfully deflect a 100 meter asteroid in a distant intercept scenario.[45] Similarly, a 100 Kton nuclear device could accommodate a 1 km asteroid while a 10 Mton device could accommodate a 10 km asteroid.[46] The best nuclear device for the purpose of NEO deflection will be an enhanced radiation design, one which provides a large flux of high energy neutrons. These are necessary to cause material blow-off from the object after irradiation by an explosion in a stand-off mode[47] (figure 13). Blast and overpressure, of course, provide no use in the vacuum of space.

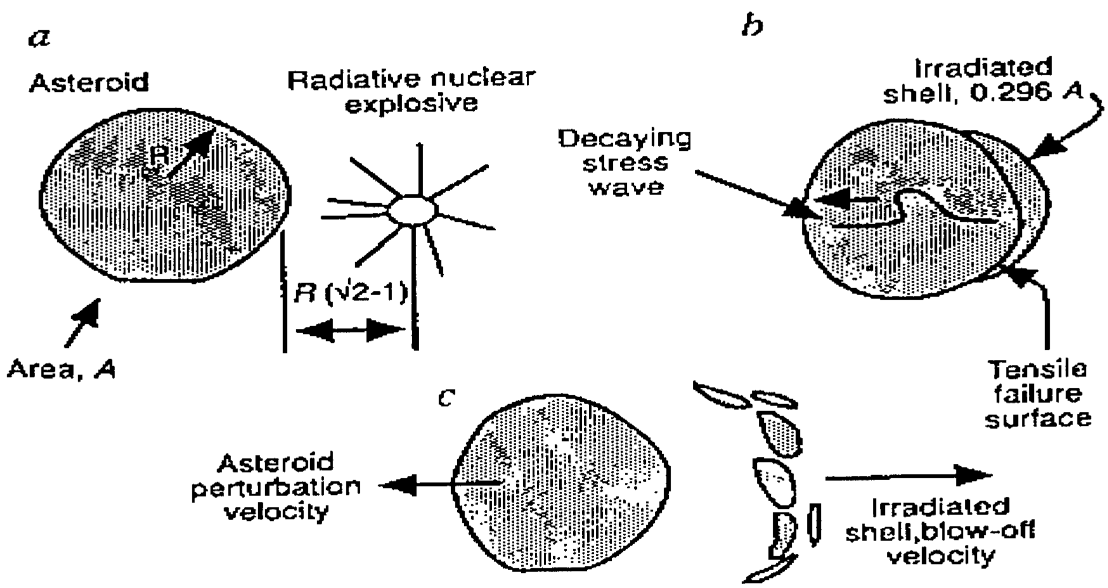

Figure 13: "How nuclear explosive radiation could be used to induce a velocity perturbation of ~ 1 cm s^{-1} in a near-Earth asteroid. *a:* Nuclear explosive designed to provide a substantial fraction, *e*, of its yield as energetic neutrons and γ-rays is detonated at an optimum height, $(\sqrt{2}-1)R$, above an asteroid. At this elevation the asteroid subtends 0.27 of the area of a unit sphere around the explosive, which irradiates 0.296 of the asteroid surface area. *b:* Irradiated to a depth of ~ 20 cm, surface material subsequently expands and spalls away from the asteroid, inducing a stress wave of several kilobars amplitude in the asteroid. *c:*

Blow-off of the irradiated shell induces a velocity perturbation of ~ 1 cm s^{-1} in the asteroid." [48]

Employment of nuclear devices in a stand-off mode represents the gentle nudge of all the options available. Though technically much more difficult, nuclear devices exploded on or beneath the object's surface impart ten or more times the impulse of a stand-off explosion.[49] This approach will require detailed knowledge of the object's composition and propensity for fragmentation, however, and may also have larger payload requirements, thus offsetting any advantage. Relative to kinetic energy options, nuclear options appear to be favored for NEOs over about 100m diameter.[50]

Other near-term options relative to the year 2020 include the use of ground or space-based lasers to induce material blow-off, and ultra-high kinetic energy devices requiring nuclear propulsion.[51] Further in the future, options include the use of antimatter,[52] large solar sails,[53] and man-tended mass drivers or reaction engines located *in situ* (e.g., a man-tended rocket attached to an asteroid as described in Arthur C. Clarke's *The Hammer of God*).[54] Finally, there could come a time for "Asteroid Eaters." In this scheme one would infest the object with a few devices whose purpose is to replicate themselves using desk-top manufacturing technology and the asteroid itself as raw material. Over the period of several months or a few years, these devices, recreating themselves into an army of thousands, could completely mine the asteroid away, or at least reduce it to a size that is no longer a threat or is more easily maneuvered by propulsion technology. A variation on this is to have these devices also mine the asteroid for fuel that a propulsion system could use to move the object into a benign orbit. Technology advances are required in desk-top manufacturing, artificial intelligence, materials permutation (molecular breakdown and alteration), robotics and micro-machines or nano-technology. Advances in these areas could lead to many spin-offs in other defense or commercial applications.

Beyond deflecting or fragmenting an errant asteroid, there may be great advantage in capturing an ECA into Earth orbit. Besides just the experience in large space operations such an endeavor would give us, great benefits could be gained through mining of the asteroid's natural resources (including its orbital energy) or use of the asteroid as a space platform for large systems used in surveillance of the near-Earth environment. An asteroid parked in an orbit slightly higher than geosynchronous might be an ideal base of operations to maintain and salvage geosynchronous communication

and surveillance satellites. Its orbit will naturally provide periodic revisit to all geosynchronous stations. A captured asteroid could also be used for large space based manufacturing or even as a space dock for buildup of interplanetary missions, eliminating the need to launch large structures from the bottom of Earth's gravity well. In summary, use of these asteroids could be stepping stones for man's future in space.

In short, there are many promising options for deflecting or fragmenting Earth-threatening asteroids and comets. The apparent best option today includes nuclear devices and perhaps nuclear propulsion. These, however, carry political ramifications we must address.

<u>Nuclear Solution/Political Fallout</u>

Though nuclear devices may well protect the Earth from threatening asteroids and comets, their employment carries heavy emotional baggage. Ironically, these devices "... could be notably straightforward to create and safe to maintain because they derive from vast research and development expenditures and experience accumulated during the forty-five years of the Cold War."[55] Technically, without an appropriate re-entry vehicle, these devices could not be used as ballistic weapons, though there is always the possibility of terrorism or misuse. In any event, effective international protocols and controls could be established through the United Nations to minimize downside potential. The debate will certainly continue, however, as evidenced by *The Deflection Dilemma:* "... the potential for misuse of a system built in advance of an explicit need may in the long run expose us to a greater risk than the added protection it offers."[56]

Near-Term Technologies and Operational Exploitation Opportunities

Near-term technologies support development of both detection and mitigation capabilities against Earth-crossing asteroids and comets. Specifically, ground-based telescopes employing CCDs with automated search techniques are viable for detection, while chemical or nuclear-propulsion rockets with kinetic energy or nuclear payloads are viable for mitigation. The challenge is not so much in technology development as in economical system design. But a further challenge, and perhaps the greatest, involves the nurturing of international coordination, cooperation, and support. The threat of NEO impact is a global problem and one which the entire world community should bear. So for the near-term, the authors' submit the following recommendation.

Recommendation

The longest journey begins with one small step. The current efforts by a few extremely dedicated individuals are commendable, but lack the national level focus and impetus to achieve the necessary results. A few farsighted predecessors led us into the true control and exploitation of the air. The authors believe the Air Force should now begin this inevitable journey into true control and exploitation of space. It should establish a project office to provide the leadership and advocacy necessary to achieve progress in this new but critical mission area.

Initially this project office will be responsible for examining and fostering capabilities to detect, track, characterize and mitigate planetary debris of sufficient size to cause significant destruction of human lives and property should it impact the Earth. To do this it will:

- Coordinate with existing efforts within DoD (if any), NASA, DOE, Academia, and others in the scientific community. It will coordinate resource support for these efforts where needed and consolidate efforts where warranted.

- Seek cooperation with and support for similar efforts in the international community and lead the efforts of the US team in the international arena.

- Advocate before Congress and international bodies the funding and fielding of an internationally supported surveillance system similar to that already proposed to Congress.

- Seek the set-aside of existing resources determined to be surplus which may aid in the surveillance and mitigation of the planetary debris threat. Specifically, this may include applicable spacelift-capable missiles and nuclear devices.

- Support the development and cross-feed of applicable technology efforts.

- Plan and program for potential future efforts to include:
  - Contingency planning for anticipated mitigation efforts.
  - Requirement definition for technology needs, emphasizing multi-use potential.
  - NEO rendezvous, characterization and deflection test missions.

For decades we have lived in fear of humanity's own destruction by the missile delivery systems and nuclear warheads designed to employ against ourselves. The authors find it somewhat ironic, but perhaps a sure indication of a divine sense of humor, that just as mankind rushes to rid ourselves of these devastating weapons, we find that we should now work together in learning to employ these same systems as the tools to deliver our planet from naturally occurring devastation.

The technology for a system to detect the threat is clearly in our grasp and only needs very modest funding to be built and put into operation. A rudimentary mitigation system could also be developed based on existing systems and maintained at modest cost compared to current defense systems. As the Clementine mission has shown, even asteroid rendezvous and characterization missions are only in the $100 million dollar range. Also, work on more sophisticated approaches will bring benefits in advanced technology in a number of defense related areas. All that mankind lacks is a greater awareness of the threat and the will to do something about it as opposed to accepting such a cataclysmic event as an act of God. This paper has attempted to increase the reader's awareness in the hope that a consensus of will might result. Mankind must now prepare for planetary defense.

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OPERATIONAL ANALYSIS

Executive Summary

This analysis was conducted to determine which of the SPACECAST 2020 systems concepts showed the greatest potential for enhancing space operations, and which of their embedded technologies have the highest leverage in making high-value systems a reality. The analytical expertise was provided by the Department of Operational Sciences at AFIT; technology assessments were done by the SPACECAST 2020 Technology Team and practical operational judgments were provided by Air War College and Air Command and Staff College faculty and students. A Value Model was developed based on Joint Space Doctrine to quantify and compare different systems' contributions to various space capabilities. The overall goal of operational analysis was to rank SPACECAST systems and their enabling technologies in a way that was traceable and reflected the value SPACECAST participants attributed to them. Thus, the model presented is an aid to senior decision makers.

Scoring the SPACECAST systems against the Value Model revealed that two system concepts were clearly ahead of the rest:

- *Transatmospheric Vehicle (TAV)*
- *Space-Based High Energy Laser System (HEL)*

These two systems scored at about the same high level, but for different reasons. The TAV contributed to virtually all space missions because it made access to space easier. The HEL scored well because it could fulfill a variety of important force application and space defense missions, and its optical system could also provide a surveillance capability. The following five systems also scored clearly ahead of the others, but below the top two:

- *Global Surveillance, Reconnaissance, and Targeting System (GSRT)*
- *Orbit Transfer Vehicle (OTV)*
- *Kinetic Energy Weapon System (KEW)*

- *High Powered Microwave System (HPMW)*
- *Particle Beam Weapon System (PB)*

The Global Surveillance, Reconnaissance, and Targeting System was assessed as a high-leverage system because of its ability to greatly enhance the capabilities of terrestrial forces. The high score of the OTV reflects the importance of improved spacelift, along with the top-scoring TAV. The next three systems are space-based weapons that scored well for reasons similar to those of the HEL. *These conclusions regarding the rankings of the systems were not affected by any reasonable changes of the weighting scheme in the Value Model.*

The study also included an assessment of the technologies on which the system concepts depend. The analysis explicitly took into account the number of systems each technology supported, the degree to which each system depended on it, and the importance of the system (but not cost or risk). Three technologies (including the two top-ranked ones) stood out because they are important to a large number of high-value systems:

- *High-Performance Computing*
- *Micro-Mechanical Devices*
- *Navigation, Guidance, and Vehicle Control*

Three other technologies were also especially important, but to a smaller range of systems:

- *Materials Technology*
- *Pulsed Power Systems*
- *Robotics, Controllers, and End-Effectors*

Advances in these areas show promise to open the way to space systems that would dramatically improve the effectiveness of space operations.

Purpose of the Analysis

SPACECAST 2020 produced a large number of system concepts which were envisioned in varying levels of detail, which provided widely different kinds of operational capabilities, and which depended on different levels of advancement in different areas beyond current technology. Clearly not all of these system concepts can be developed, nor can all of the technologies be aggressively pursued. The Air Force needs to prioritize the relative importance of both space systems and technologies. This operational analysis was conducted to answer two basic questions:

1. Which of the SPACECAST 2020 system concepts offer the greatest promise of increasing operational effectiveness?

2. What are the technologies that offer the greatest leverage in turning high-value system concepts into operational realities?

Challenge

This operational analysis presented two major technical challenges. The first was that it required estimating the performance of future space systems that are incompletely defined and which often rely on technology that does not yet exist. This meant that inevitably the only data available by which to evaluate them were qualitative human judgments. The team's approach to this challenge was to break the analysis down into many separate evaluations. Even though some individual judgments may lack rigorous precision, the weighted sum of all the judgments will have enough precision for the purposes of the analysis.[1] The second major challenge came from the fact that the analysis required comparison of alternatives that are inherently different sorts of things. For instance, the system concepts included space launch systems, weapon systems, and surveillance systems. It was necessary to rate these different concepts on some sort of common scale so that they could be compared to one another. The team's approach was to score the alternatives according to their estimated contribution to *operational effectiveness*, with effectiveness in different areas of space operations being weighted according to their value with respect to space operations as a whole. The details of the methods used to face these two challenges are described below (see "Methodology").

In addition to these technical challenges, the analysis team operated under some practical limitations. The conclusions of this analysis should be considered with these limitations mind. These were the following: the White Paper system, the Joint Space Doctrine framework, the members of the team, and the time available.

The ground rules of the study were to evaluate the systems and technologies presented in a given set of White Papers. Consequently, the scope of the study was limited to those systems and technologies. It is possible that other important systems could be developed, which would draw attention to other technologies. These could be evaluated using the methodology of this study. However, the scope of this study was limited to the SPACECAST White Papers presented.

The team used the framework of current Joint Space Doctrine to develop the Value Model. While this provided an excellent start, it is based on *current* ideas about space operations. It did not allow evaluating systems' contributions to space missions that are not currently envisioned.

The analysis relied to a large extent on human judgments about the systems and technologies. These judgments came from a broad selection of students and faculty from the Air Force Institute of Technology, the School of Advanced Airpower Studies, Air War College, and Air Command and Staff College. The collective experience, knowledge, and judgment of these individuals were vital to the successful outcome of the study. Finally, the analysis had to be completed within a time period of about four weeks. This is an extremely short time for a problem of this complexity.

Methodology

There is a wide range of techniques that can be used to approach a problem like this. The most important tradeoff in picking a technique is that of depth of analysis versus time. At one extreme, a group of experts can review the alternatives for a while and give a subjective ranking of them. At the other extreme, a full Cost and Operational Effectiveness Analysis can be done, as is usually done before starting development of a major new program. The analysis team selected an approach called Value-Focused Thinking as most appropriate for the task at hand.[2] It allowed the alternatives to be evaluated at an appropriate level of detail, considering their level of definition, and could

be completed within the time available for analysis. Value-Focused Thinking requires creating a Value Model of the qualities that are valued in the alternatives. In this analysis, the *alternatives* were the proposed system concepts and the *qualities* were various measures related to operational effectiveness in space. This Value Model takes the form of a hierarchy, starting from broad categories at the top level and specifying the desired qualities in greater detail at lower levels, striving for qualities that are as concrete as possible and where possible quantifiable. The alternatives are then scored against the qualities at the lowest level of the hierarchy. The qualities are assigned weights based on their *overall* contribution to the value system, and an alternative's final score is found by multiplying its quality scores by the appropriate weights and summing over all qualities. This gives a rational, traceable, objective, and quantifiable basis for ranking the alternatives. In this analysis, a single system that makes revolutionary contributions to a very narrow area of activity may score lower than a system that makes contributions to a large number of areas.

In addition to ranking the system concepts, the operational analysis also had to identify high-leverage technologies whose advancement offers the greatest promise of increasing the effectiveness of space operations. To address this part of the problem, the analysis team evaluated each system concept on the degree to which it depended on advances in various technologies. This produced a system-versus-technology weight matrix. By multiplying it with system scores derived from the Value Model, the relative weights for the technologies were found. This provided a comprehensive method of ranking the various technologies according to the degree to which they supported the most important system concepts. In order to reduce the technology ranking problem to a manageable size and to focus on its most essential features, a few modifications were made to this procedure, as will be described below.

In summary, this was the general method of the analysis: A Value Model was devised to define the desired force qualities. All systems were scored against all qualities, producing a system-versus-quality matrix. The scores were multiplied by the quality weights and summed, giving system scores. This scoring was used to rank the different system concepts. In addition, a system-versus-technology matrix was developed as described in the preceding paragraph. When multiplied by the system scores, this provided a ranking of the technologies.

Developing the Value Model

The value model hierarchy was based on JCS PUB 3-14, *Military Space Doctrine*. That document states that the overall goal of military space operations is to control and exploit space. It provides the top two levels of a value hierarchy for space operations: it lists four basic types of space operations:

Force Enhancement:	Assisting terrestrial military forces
Force Application:	Applying military force for ballistic missile defense, for defense of terrestrial forces, or directly against enemy targets
Space Control:	Monitoring space activity, defending against attacks in space, and negating hostile space systems
Space Support:	Launch, satellite control, and logistics operations

In addition, each area of operations is divided into appropriate force capabilities. For instance, under Force Enhancement there are Communications; Navigation and Positioning; Intelligence and Surveillance; Environmental Monitoring; Mapping, Charting, and Geodesy; and Warning, Processing, and Dissemination.[3] There were advantages and disadvantages to using this structure. The major disadvantage was that it did not include a few possible future space missions, such as planetary defense against asteroid impact. On the other hand, it provided an official and authoritative doctrinal architecture that was comprehensive enough to include all current and the most important future space missions. This seemed to be the best available starting place for the Value Model.

Each of the force capabilities from JCS PUB 3-14 was analyzed further to provide a listing of force qualities. These force qualities were the most important characteristics required for operational effectiveness in each capability. As far as possible they were selected to be concrete and measurable. For instance, the force qualities defined under Communications were Crisis Availability, Capacity, Interoperability, and Security. These force qualities provided a third and in some cases a fourth level of the value hierarchy. An illustration of the top levels of the hierarchy is shown in Figure 1. The

complete Value Model is found in the first six columns of the matrix in Appendix 1. The final hierarchy had 98 detailed force qualities or *line items* at the lowest level of the hierarchy.[4] It was these line items at the lowest levels of the hierarchy that were used to develop measures of merit against which the systems were scored (see "Scoring the Systems").

<table>
<tr><th colspan="11">OVERALL OBJECTIVE: CONTROL AND EXPLOIT SPACE</th></tr>
<tr><th colspan="8">Force Enhancement</th><th rowspan="4">Force Application</th><th rowspan="4">Space Defense</th><th rowspan="4">Space Support</th></tr>
<tr><td colspan="4">Communications</td><td rowspan="3">Navigation and Positioning</td><td rowspan="3">Intelligence and Surveillance</td><td rowspan="3">Environ-mental Monitoring</td><td rowspan="3">Mapping, Charting, and Geodesy</td></tr>
<tr><td>Crisis Availability</td><td>Capacity</td><td>Inter-operability</td><td>Security</td></tr>
<tr><td>Measure of Merit</td><td>Measure of Merit</td><td>Measure of Merit</td><td>Measure of Merit</td></tr>
</table>

Figure 1: Value Hierarchy

Leftmost Branches Expanded

In addition to defining a value hierarchy, it was necessary to assign relative weights to the line items. The challenge here was to assign relative weights in a sensible way to force qualities that are different. This was done by assigning weights at each level of the hierarchy. First, weights were assigned at the top level, to each of the four areas of military space operations. Then for each of the four, weights were assigned for the subordinate force capabilities, and so on down the hierarchy. To make the workload manageable, subteams were asked to look at every branch point and estimate the relative weights of the items at the next level.[5] Each weighting was reviewed by a high-level team, occasionally modified slightly, and incorporated in the larger model. The weights were normalized, i.e. scaled so that all the weights at any one level sum to one. The weight of each line item is then the product of all its inherited weights up the hierarchy. As a mathematical consequence of the normalization, the weights of all line items sum to one.

The "standard" value weights are listed in the Value Model in the first six columns of the matrix in Appendix 1. These values represent the team's judgment of the relative value of the force qualities if the future geopolitical system is more or less similar to today (the "SPACECAST 2020 Standard World"). The weights were also estimated for a "Rogue World" scenario, a world in which there are one or a few aggressive, militarized, and sufficiently technologically capable states that are the main threat to world peace. These weights are in Appendix 2. Other weights were also used when performing a sensitivity analysis, as described below (see "Key Results").

System Identification

Following a thorough review of the SPACECAST 2020 White Papers, the Technology Team identified 19 unique high-leverage space systems (listed in Appendix 3) from which key technology areas could be identified. For this operations analysis, a system was defined to be "a functionally related group of elements that performs a mission or task." Although most of the identified systems were each extracted from a single white paper, several systems, particularly those involving space weaponry, were critical to the capabilities detailed in several of the papers. For example, space-based high energy laser systems were key elements of the white papers on offensive counterspace, defensive counterspace, and force application, and also contributed heavily to the capabilities called out in the paper entitled "Leveraging the Infosphere: Surveillance and Reconnaissance in 2020." In several of the papers, such as the one

entitled "Projecting Information Power in War and Peace," no systems could be identified. In these cases, the papers contained a general framework for doing business in given mission areas without a level of detail required for technology identification.

The 19 identified systems were:

1. Spacelift Transatmospheric Vehicle (TAV, nicknamed Black Horse)
2. Orbit Transfer Vehicle (OTV)
3. Orbital Maneuvering Vehicle (OMV)
4. Space Modular System
5. Global Surveillance, Reconnaissance and Targeting System (GSRT)
6. Super Global Positioning System (S-GPS)
7. Space Traffic Control System (SPATRACS)
8. Weather Forecast System
9. Space-Based Solar Monitoring and Alert Satellite System (SMASS)
10. Ionospheric Forecasting System
11. Holographic Projector
12. Space-Based High Energy Laser System (HEL)
13. Kinetic Energy Weapon System (KEW)
14. High Powered Microwave System (HPMW)
15. Particle Beam Weapon System (PB)
16. Weather C3 System
17. Solar Mirror System
18. Asteroid Detection System
19. Asteroid Negation System

The full descriptions of these systems are found in Appendix 3.

Scoring the Systems

Scoring 19 systems against 98 line items required 1862 judgments to be made. A structure was developed to maximize the consistency and objectivity of the judgments. Before any systems were scored, a ***measure of merit*** was defined for each line item. This was a specific and where possible quantifiable measure of that quality, such as "megabits per second" or "pounds to orbit." (In a few cases a line item was given two measures of

merit.) Four benchmark levels of operational capability were established for each measure of merit, as shown in the following table:

Operational Capability	Score
Current	1
Minor Improvement	2
Significant Improvement	6
Order-of-Magnitude Improvement	10

For instance, the measure of merit for line item 2 (communications capacity) was "decompressed megabits per second" on a satellite communications link. The team's assessment was that a typical current figure was 300 megabits per second, a minor improvement would be 600 megabits per second, a significant improvement would be one gigabit (1,000 megabits) per second, and three gigabits per second per link would be an order of magnitude improvement. These assessments relate the measure of merit to operational effectiveness, and an order of magnitude improvement in effectiveness may not occur at the same point as an order of magnitude (factor of 10) increase in the raw measure of merit. These assessments were connected to a normalized numerical scale by equating current capabilities to 1, minor improvements to 2, significant improvements to 6, and order of magnitude improvements to 10. Both the measures of merit and the operational effectiveness benchmarks were developed by the teams of Air University students and faculty that defined the Value Model. Once the scoring scale had been established in this way, the 19 systems were each scored according to its capability to contribute to the 98 force qualities that the team identified.[6]

Short descriptions of the measures of merit and the four benchmark levels of each are presented in columns 7 through 11 of the matrices in Appendix 1. Full descriptions of the unclassified measures of merit are in Appendix 4. The scores of each system on each line item are listed in Appendix 5, which also gives the systems' raw scores. (For technical reasons it was convenient to use a scale running from zero to one hundred percent when doing the score calculations. These are the scores shown in the appendices. However, in the Value Model of this analysis, a low score corresponds **not** to *zero* capability but to *current* capability. After the system scores were calculated on the zero-to-one scale, they were re-scaled so that they fell into the more intuitive range where 1.0 represents "current capability" and 10.0 represents "order of magnitude improvement.")

Two systems could not be scored because they did not fit into the structure of the Value Model. These were the Holographic Projection (#11) and Asteroid Negation (#19) systems. The team's judgment is that these systems are so far in the that the inability to score them did not affect the validity of the analysis.

Technology Identification

Once the 19 unique systems contained in the white papers were identified, the SPACECAST 2020 Technology Team qualitatively analyzed each system to identify which technology development areas would be key to achieving the stated system capabilities. The team felt that it was highly desirable to identify and group technologies according to a well-known "gold-standard." Thus, the DoD document entitled *The Militarily Critical Technologies List* (MCTL) was used as the basis for key technology identification in each system.[7] For the 19 systems evaluated, a total of 25 key technology areas (listed in Appendix 6) were identified. One technology area, virtual reality, was repeatedly mentioned in numerous white papers, but was not explicitly identified in the MCTL document. Although called out as a specific technology area, virtual reality is in actuality a combination of several of the technologies called out in the MCTL guide.

Following are the key technologies identified (full descriptions are in Appendix 6):

1. Data Fusion
2. Electromagnetic Communications
3. Energetic Materials
4. Hard Real-Time Systems
5. High Energy Laser Systems
6. High Performance Computing
7. High Power Microwave Systems
8. Image Processing
9. Information Security
10. Kinetic Energy Systems
11. Lasers
12. Liquid Rocket Propulsion
13. Materials Technology
14. Micro-mechanical Devices

15. Navigation, Guidance, and Vehicle Control
16. Neutral Particle Beam (NPB) Systems
17. Nonchemical High Specific Impulse Propulsion
18. Optics
19. Power Systems and Energy Conversion
20. Pulsed Power Systems
21. Robotics, Controllers, and End-Effectors
22. Sensors
23. Spacecraft Structures
24. Vehicle Survivability
25. Virtual Reality

In order to eventually rank technologies by their impact on future space capabilities, the team assigned a relative weight to each technology embedded in a particular system as shown in Appendix 7. The weights selected sum to 100 for each system, and so can be thought of as percentages of the system's dependence on each technology. For example, the five Orbital Transfer Vehicle (OTV) technologies were weighted as follows:

Technology	Weight
Nonchemical/High Specific Impulse Propulsion	40
Power Systems and Energy Conversion	20
Micro-mechanical Devices	20
Robotics, Controllers, and End-Effectors	15
Materials Technology	5

In this case, since the primary mission of the OTV is to act as a space "tug" for moving satellites between higher and lower orbits, the highest-leverage technology area is that of the vehicle's primary propulsion subsystem. The other four technologies, although still critical to effective system performance, were of lesser leverage than that of the primary propulsion subsystem. Using this methodology, once all of the systems were scored in the model, the 25 technology areas could be ranked as to their overall impact on future space operations.

Scoring the Technologies

Once the system-versus-technology matrix is in hand, the procedure for scoring the technologies is straightforward. For each technology, its contribution to each system is multiplied by the system score, and the resulting products are summed across all systems. The result is a set of technology scores (in arbitrary units) that takes into account both the technologies' degree of contribution to future space systems and the importance of those systems to space operations.

Key Results

Scoring the Systems

The results of the system scoring are summarized in Figure 2. The vertical axis is the rescaled score from the system evaluation (1.0 represents current capability; 10.0 would represent an order of magnitude improvement in operational effectiveness across *all* force qualities). The horizontal axis is a rank ordering of the systems according to the team's assessment of the degree of advance in current technology the system would require. This is not a quantitative measure; it was done to give an impression of how far in the future the systems lie.[8] The system scores are shown using the "SPACECAST Standard World" weights, the Value Model force quality weights that the team felt were most likely to represent the most likely future. The system scores were also calculated using four other weighting schemes. The first was the Rogue World weights. Three were taken by changing the weights at the highest level of the hierarchy to represent the extreme views of members of the team. The sets of weights were chosen that put the most weight on Force Enhancement (FE) and on Force Application (FA), plus a scheme that put no weight on Space Support (SS). Finally, a survey was given out to Air University students asking them to provide top-level weights and the 44 responses were averaged. The results of all these different weight schemes are shown in Table 1. The resulting spread of scores for each system can be regarded as similar to error bars in the results of a statistical sampling technique. In other words, a system's score can be said with high confidence to lie within the range of the points shown. A comparison of the scores using the six different weighting schemes is shown in Figure 3.

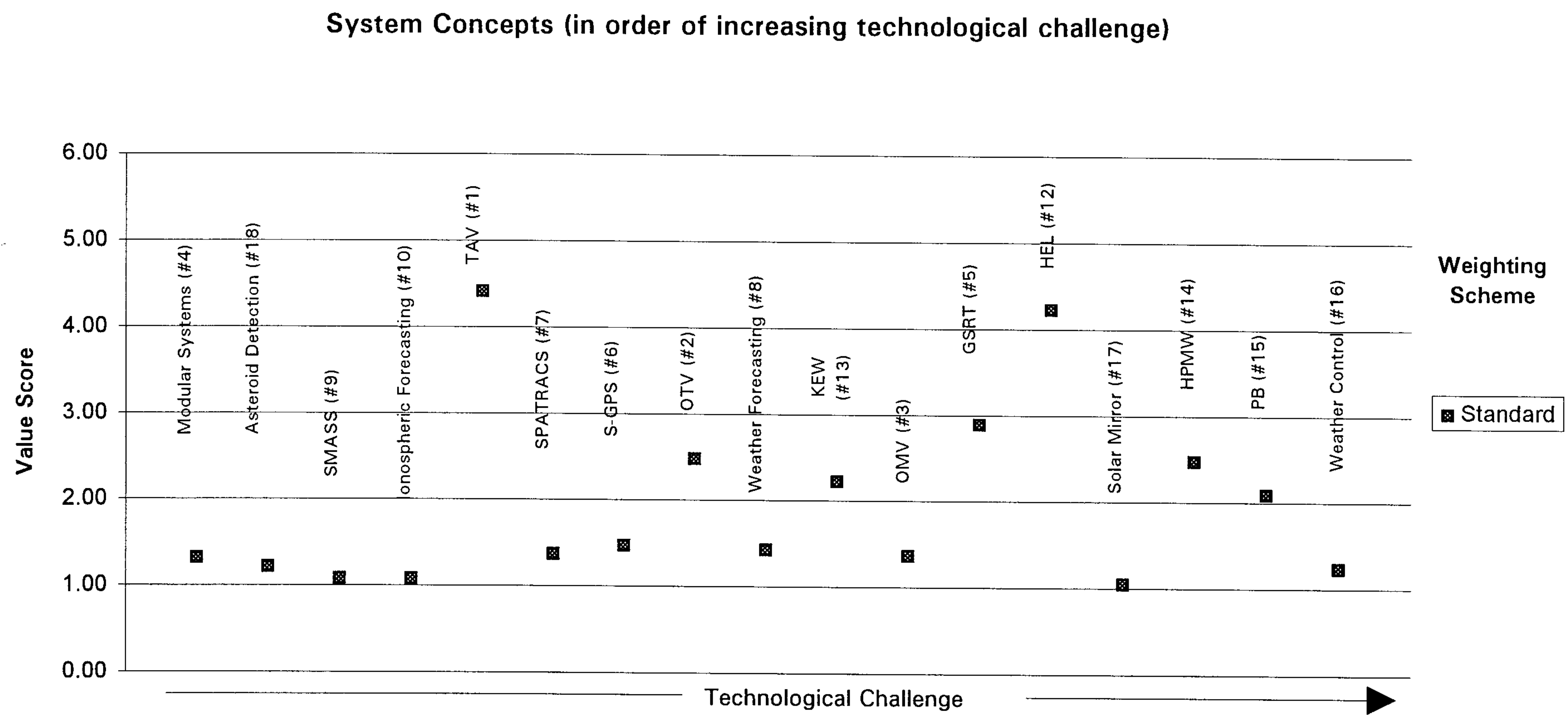


Figure 2: SPACECAST 2020 Operational Analysis Summary

Table 1. Sensitivity Analysis Weighting Schemes

Scheme	Force Enhancement	Force Application	Space Control	Space Support
Standard	0.37	0.19	0.22	0.22
Rogue World[9]	0.31	0.21	0.31	0.17
High FE	0.40	0.10	0.30	0.20
High FA	0.30	0.25	0.20	0.25
Low SS	0.48	0.24	0.28	0.00
Survey	0.31	0.22	0.22	0.25

FE= Force Enhancement
FA= Force Application
SS= Space Support

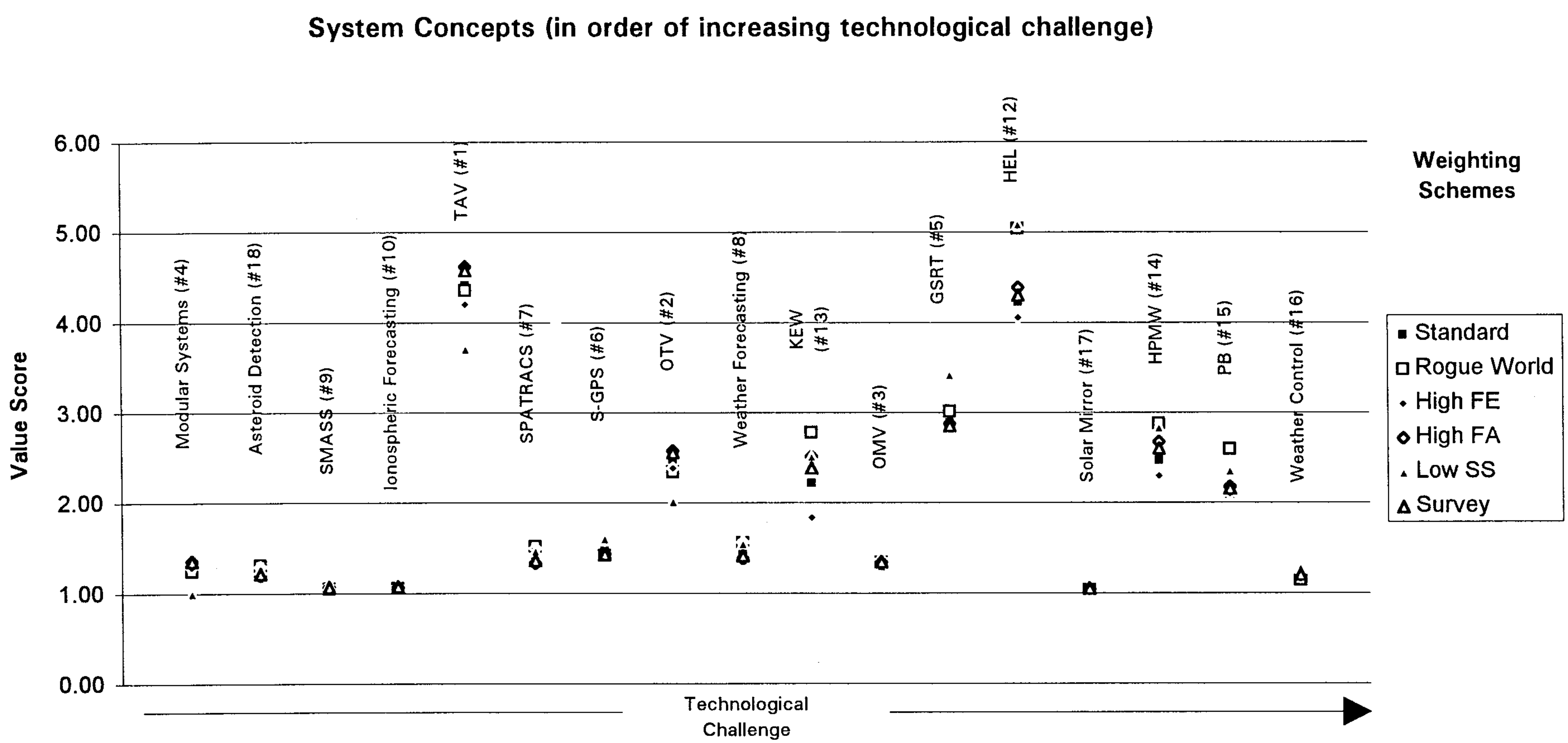


Figure 3: System Scoring Sensitivity Analysis

The most important result of the analysis is that the systems can be divided into three groups based on their scores. The Transatmospheric Vehicle (#1) and the Space-Based High Energy Laser (#12) both scored generally in the range of 4 to 5. Five other systems scored generally in the range of 2 to 3: the Global Surveillance, Reconnaissance and Targeting System (#5), the Orbit Transfer Vehicle (#2), the Kinetic Energy Weapon (#13), the High Powered Microwave (#14), and the Particle Beam Weapon (#15). All other systems scored between 1.0 and about 1.6. This result was very robust to changes in the weighting scheme. The TAV scored high because it was assessed as a strong contributor to most space capabilities by making spacelift easier. The High Energy Laser System scored better than the other space-based weapon systems because the system concept including using the laser's optics as an imaging device, so the system contributed to surveillance-related areas as well as to Force Application and active Space Control. In the second group of systems, the GSRT scored in highest because it is such a strong contributor to the Force Enhancement area, the most important part of the overall space mission in all weighting schemes. The three space weapons (KEW, HPMW, and PB) score well because they also contribute to high-priority missions in Force Application and Space Control. The OTV has a similar score because it contributes to all missions, though in a more limited way than the TAV. The remaining systems typically scored lower because their contributions were only in narrow ranges of mission areas and force qualities.

Scoring the Technologies

The results of the scoring of the technologies are summarized in Table 2. Because seven of the system concepts strongly outscored the other twelve, the team decided to simplify the analysis of the technologies by considering their interaction only with the seven top-scoring systems. The score for each technology was calculated by multiplying the percentage dependence of each of the systems on that technology by the score that system received in the Value Model, then summing across the seven systems.[10] Table 2 lists 20 technologies in order of their scores; five technologies did not contribute to the seven top systems.[11] The scores in Table 2 are measures (in arbitrary units) of the potential of each technology to improve operational effectiveness in space, and can be used to compare the technologies to each other.

Critical Technologies	System Dependence on Technologies (percent)							Weighted Technology Score
	TAV (#1)	OTV (#2)	GSRT (#5)	HEL (#12)	KEW (#13)	HPMW (#14)	PB (#15)	
High Performance Computing (#6)	20		20	5	20	5	5	15.9
Micro-mechanical Devices (#14)	5	20	10	5	15	5	5	11.3
Materials Technology (#13)	30	5						11.0
Pulsed Power Systems (#20)						40	40	10.2
Nav., Guidance, and Vehicle Control (#15)	10			5	25	5	5	9.3
Robotics, Controllers, and End-Effectors (#21)	20	15						9.0
Lasers (#11)				25				8.1
Optics (#18)				25				8.1
High Energy Laser Systems (#5)				25				8.1
High Power Microwave Systems (#7)						45		6.6
Power Systems and Energy Conversion (#19)		20		10				6.2
Nonchem. High Specific Impulse Prop. (#17)		40						5.9
Neutral Particle Beam (NPB) Systems (#16)							45	4.9
Kinetic Energy Systems (#10)					40			4.9
Sensors (#22)			25					4.7
Data Fusion (#1)			20					3.8
Energetic Materials (#3)	10							3.4
Image Processing (#8)			15					2.8
Electromagnetic Communications (#2)			10					1.9
Vehicle Survivability (#24)	5							1.7
Total	100	100	100	100	100	100	100	

Table 2: Technologies Scored against Top 7 Systems

Perhaps the most important result of the analysis is the high scores received by High Performance Computing, Micro-mechanical Devices, and Navigation, Guidance, and Vehicle Control (15.9, 11.3, and 9.3, respectively). These three technologies were each important to five or more of the top seven systems. Their high scores are the result of the broad applicability of these technologies to high-value systems. This is a significant result. All other technologies contributed to only one or two high-value systems. Of these, the high-scoring ones were Materials Technology (11.0), Pulsed Power Systems (10.2), and Robotics, Controllers, and End-Effectors (9.0). The rest of the technologies scored 8.1 or lower and showed no tendency to occur in groups.

Launch System Study

Only one launch system was represented among the 19 system concepts, but that system (the TAV, Black Horse) scored very highly. The analysis team felt that more exploration of alternative launch systems was called for. Accordingly, they scored five additional current and proposed launch systems: the current Delta II 7925, the Russian Zenit, the proposed Delta Clipper single-stage-to-orbit (SSTO) vehicle, a derivative of the National Aerospace Plane (NASP) using supersonic combustion technology, and a two-stage-to-orbit (TSTO) design launching from a carrier aircraft and called "White Horse" to contrast it to the SPACECAST "Black Horse." More complete descriptions of these launch systems are found in Appendix 8. The results of scoring these systems are summarized in Figure 4; the complete data are in Appendix 9. The "Standard World" weighting scheme was used. Delta II 7925 and Zenit are essentially current systems, and their scores showed only moderate gains over current practice. Zenit was assessed as significantly more effective than Delta because of better responsiveness, logistics, and support to space missions. The other three systems scored substantially better, all being in the 4.3 range along with the Black Horse TAV that was among the original systems. These four fully reusable lift systems score similarly because they offer similar advantages over current launch systems. The differences between their scores are probably not significant.

The analysis team also felt that some of the spacelift systems should be considered together because they could be expected to work synergistically if deployed together. In particular, the Transatmospheric Vehicle provides excellent access to near-Earth orbit, while the Orbital Transfer Vehicle provides easy access between low-,

medium-, and high-altitude orbits. The two systems together would provide efficient access to all militarily important regions of space. In addition, the Space Modular System (#4) dramatically improves the ease and flexibility of operations in orbit. The team decided to explore the possibility of combining the three systems, and rated them in combination (using the "Standard World" weighting scheme). The results are summarized in Figure 5, and the complete scoring data are in Appendix 10. The "TAV + OTV" and "TAV + OTV + Modular Systems" combinations outscored any of the 19 single systems. This result illustrates the synergism possible when related systems are combined. However, the combinations offered so much operational capability that the team felt they had difficulty giving them a fair rating within the structure of the Value Model. One should keep in mind that the Value Model was designed to rate single systems. The team feels that these results probably underestimate the true synergism between TAV, OTV, and Modular Systems. In other words, a more detailed analysis of these combinations would probably score them even higher.

Figure 4: Launch System Study

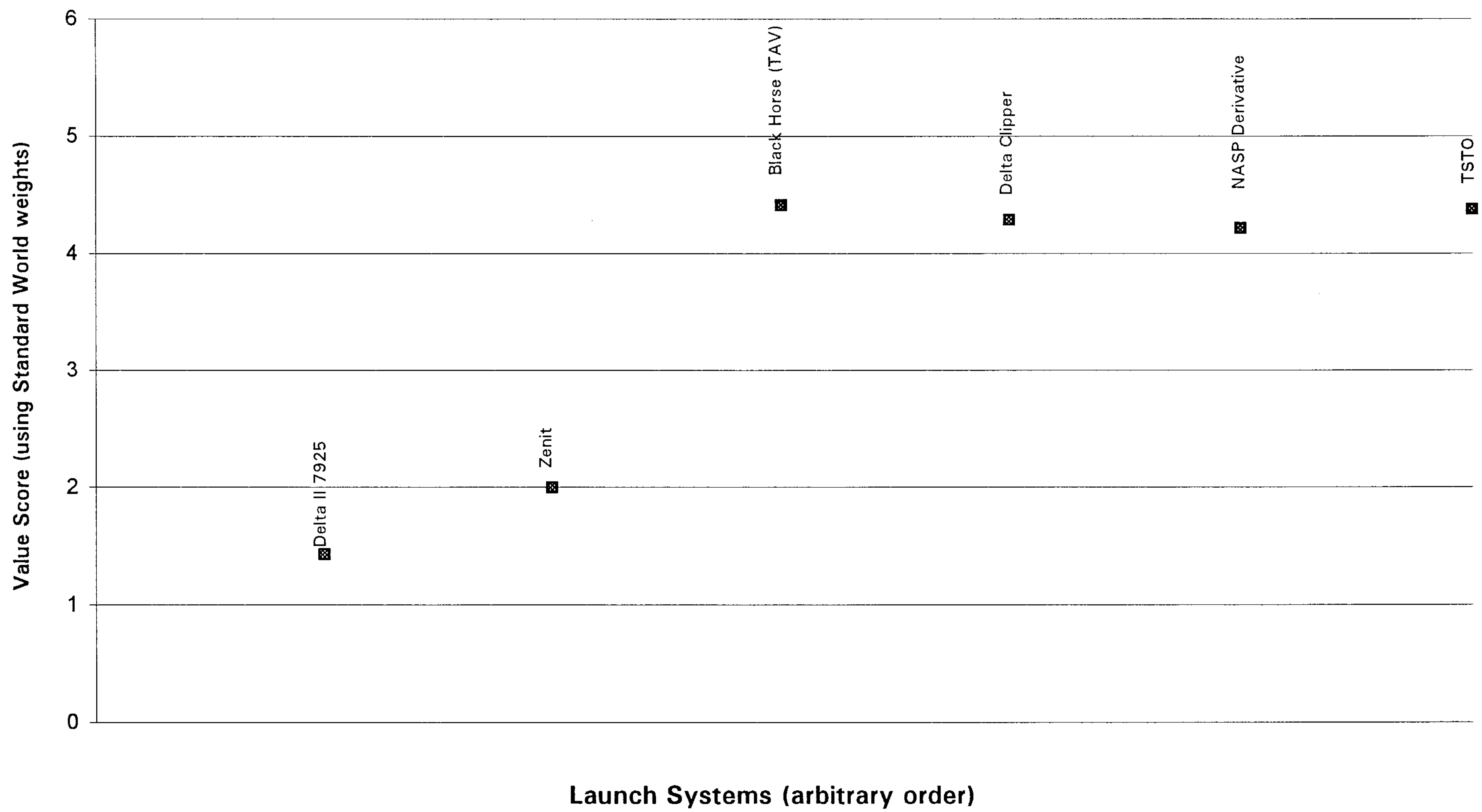
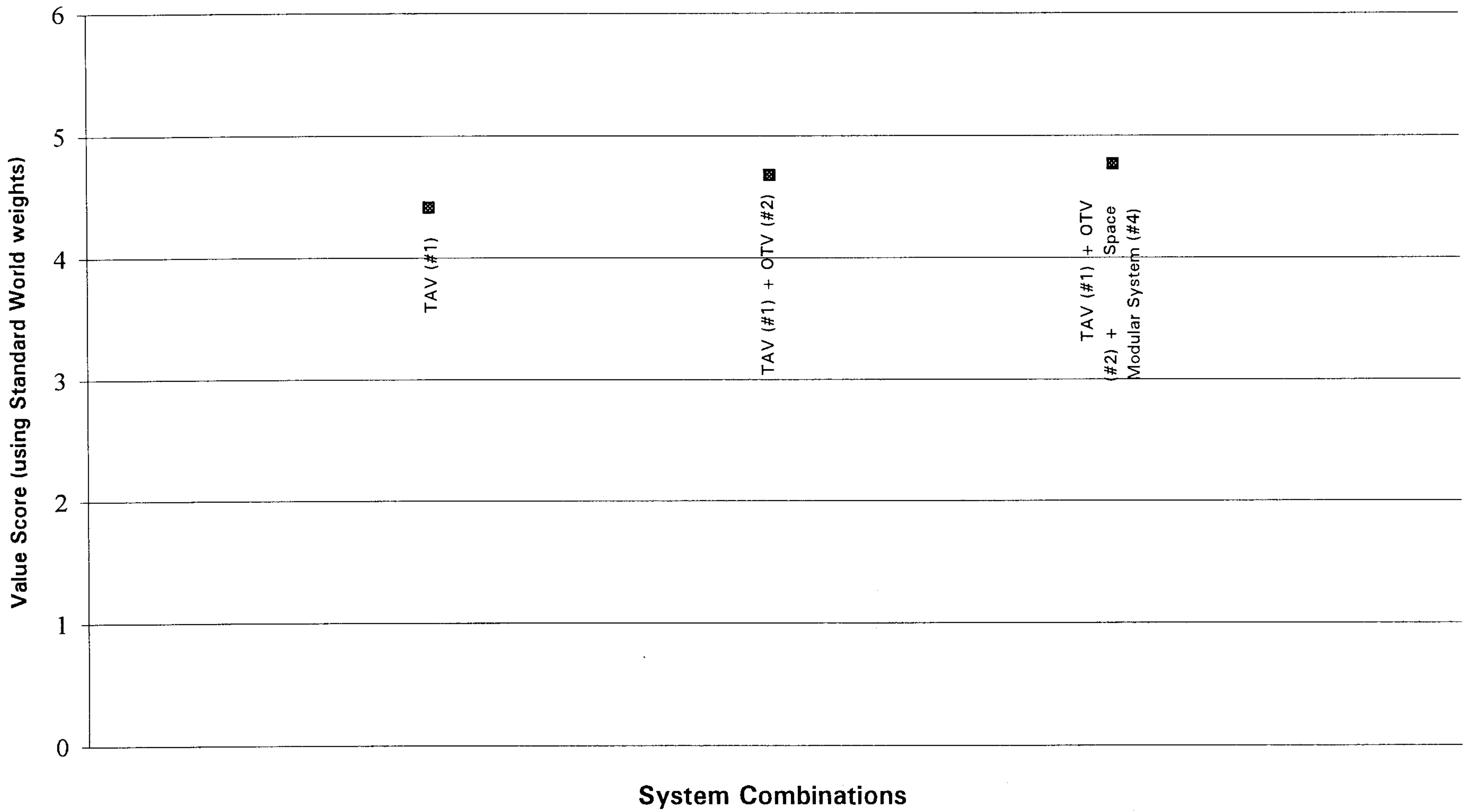


Figure 5: Combined Spacelift Systems



Conclusions

This analysis clearly showed that *improved spacelift* is one of the most important contributors to future space operations. The most important area here is an improved space launch capability, as exemplified by the reusable Black Horse Transatmospheric Vehicle. Various other advanced launch systems show equal promise: the Delta Clipper, a NASP-derived vehicle, and an aircraft-boosted two-stage-to-orbit system. Such an improved lift capability is important because it improves virtually all space force capabilities. An orbital transfer vehicle is also important for improving spacelift to high-altitude orbits.

This analysis also showed that *space-based weapons* are at the highest level of importance as contributors to the overall operational efficiency of future space operations. They are important because they provide to important capabilities in ballistic missile defense, defense of terrestrial forces, terrestrial power projection, and active space defense. Of the weapon systems evaluated, a High Energy Laser seems to hold the most promise, largely because its optical system could also be used for some surveillance and imaging missions. Other systems that scored well were a Kinetic Energy Weapon, a High Powered Microwave, and a Particle Beam Weapon.

The final system that stood out in the analysis was the *Global Surveillance, Reconnaissance, and Targeting System.* This system contributes strongly to the Force Enhancement capabilities of space systems. Such a system provides a global view that could revolutionize terrestrial military operations.

The technology assessment portion of the study discovered three critical technologies that are important to a large number of high-scoring systems. These included the two technologies that were the top scorers over all. The three technologies are:

- *High-Performance Computing*
- *Micro-mechanical Devices*
- *Navigation, Guidance, and Vehicle Control*

It was an unexpected and important result of the study that these technologies (particularly Micro-Mechanical Devices) scored so highly in the technology evaluation.

Advances in these areas show promise to substantially improve a wide range of space operations. Other technologies were also important, but contributed to only one or two of the high-value systems. Among the top-scoring technologies were:

- *Materials Technology*
- *Pulsed Power Systems*
- *Robotics, Controllers, and End-Effectors*

Other technologies scored nearly as well; see Table 2 for the complete list.

It is important to remember that the analysis did not take into account the cost of developing or deploying any of the system concepts. It also looked only briefly at the risk or technological challenge of developing them (as for instance in Figure 3). This was because of the lack of data to support such an analysis, and also because of the SPACECAST 2020 charter to be visionary and future-oriented. While this study indicates some systems and technologies that show promise for dramatically improving the effectiveness or efficiency of space operations, there are other important things that need to be considered before making an investment decision. These include cost and risk.

Some of the high leverage technologies enabling SPACECAST systems, such as high performance computing, are being pursued aggressively in the private sector. Others, such as pulsed power systems, may have lower commercial utility. Further analysis of the SPACECAST systems and their embedded technologies can point the way to an investment strategy that maximizes the defense appropriation. These decisions are beyond the scope of the SPACECAST charter.

Finally, the SPACECAST operational analysis model is only a first step. It is offered as a starting point for further elaboration, quantification, and refinement. Operational analysis completes the SPACECAST process that began with creative thinking, by assessing what creative thinkers envisioned would make valuable contributions to national security in the far future.

Notes

[1]The technical justification for this is found in the Law of Large Numbers.
[2]Ralph L. Keeney, *Value-Focused Thinking: A Path to Creative Decisonmaking* (Cambridge, MA: Harvard University Press, 1992).
[3]JCS PUB 3-14, *Military Space Operations*, Table III-1.
[4]The line items were numbered from 1 to 101, with numbers 10, 14, and 20 not used.

[5]Some of the weights show more precision than can be justified in a judgment-based study. This is because in some cases the team members were close but not identical in their judgments and agreed to take an average. This results in a spurious impression of precision, but is otherwise harmless.
[6]It was difficult to directly score some systems against the measure of merit. For instance, an improved launch system will clearly affect line item 1 (which refers to the number of satellite communications links available) by making it easier and quicker to launch the satellites, but it is difficult to say by how much. Since the purpose of the analysis was to evaluate the potential future benefit of new technology, the team's practice was to score generously when such judgments were called for. Each system was given a score corresponding to its greatest reasonable contribution to the measure in question.
[7]*The Militarily Critical Technologies List*, Office of the Under Secretary of Defense for Acquisition, Washington, D.C., October 1992.
[8]Two systems were not scored because they did not fit into the structure of the Value Model based on JCS PUB 3-14. These were Asteroid Negation and Holographic Projection. They were both assessed as requiring major technology breakthroughs to become effective.
[9]The Rogue World weighting scheme included some changes in the lower levels of the Value Model hierarchy, as shown in Appendix 2.
[10]For this calculation the non-rescaled Standard World system score was used. This is the raw score falling in the range of zero to one hundred percent and shown in Appendix 5.
[11]These technologies were Hard Real-Time Systems (#4), Information Security (#9), Liquid Rocket Propulsion (#12), Spacecraft Structures (#23), and Virtual Reality (#25).

SPACECAST 2020 VALUE MODEL			27 May 94						
Hierarchy with weights (Spacecast 2020 "Standard World"):									
				Line		Current	Minor	Significant	Order of
OVERALL OBJECTIVE: Control and Exploit Space				Item		Level	Improvement	Improvement	Magnitude
				No.	Measure of Merit	(0.0)	(0.1)	(0.5)	(0.9)
		Crisis availability	0.35	1	Initial # links in theater	about 10	25	100	1000's
	Communications	Capacity	0.35	2	Decompressed MB/sec	300 Mbits/sec/link	600	1000	3000
	0.22	Interoperability	0.20	3	Common-use systems	Little	All AF systems	All US systems	US, commercial, intl.
		Security	0.10	4	Level of secure links	Corps	Division	Battalion	Platoon
		Availability	0.10	5	Crisis Availability	Very good	100%	--	--
	Navigation &	Data availability	0.25	6	Receiver size/cost	Handheld/$1000	Handheld/$100	Wristwatch/$50	On one chip
Force	Positioning	Accuracy	0.25	7	Location precision	10 m	1 m	1 cm	--
Enhance-	0.20	Robustness	0.40	8	Resistance to CM	None (common user)	Antijam	Antijam, antispoof	AJ, AS, antivirus
ment		Processing Speed	0.36	9	Auto image processing	Some change det.	Search, recognition	Humans for review only	Full auto report to user
	Intelligence &			10	(not used)				
0.37	Surveillance	ID Capability	0.21	11	Image interpretability	(classified)	(classified)	(classified)	(classified)
	0.25	Coverage	0.14	12	Area per unit time	(classified)	(classified)	(classified)	(classified)
		Day-night, All Weather	0.29	13	% time data available	(classified)	(classified)	(classified)	(classified)
				14	(not used)				
	Environmental	Spectral Bands	0.20	15	Multispectral bands	5	10	100's	1000's
	Monitoring and	Weather Prediction	0.20	16	Prediction	24 hrs	3 day	1 week	1 month
	Control	Multispectral Coverage	0.20	17	Multispectral revisit time	7 days	5 days	1 day	Hours
		Weather Detail	0.20	18	Instant WX info	Cloud cover	Clouds + precipitation	Clds + precip + winds	--
	0.07	Weather Control	0.20	19	Amount of control	--	Clear fog	Modify patterns	Weather on demand
	Mapping,			20	(not used)				
	Charting, &	Surface Characterizatn	0.31	21	Amount of detail	Surface terrain	Trafficability	All structures	Full resource characteriztn
	Geodesy	Mensuration	0.31	22	Geodetic precision	(classified)	(classified)	(classified)	(classified)
	0.08	Data availability	0.38	23	Time to get new map	Months	1 month	1 week	1 day
		Coverage	0.20	24	Coverage	Ltd global ICBM	Ltd global MRBM	Global MRBM	Global SRBM/cruise
	Warning,	ID Capability	0.30	25	What and where	(classified)	(classified)	(classified)	Missile type and target
	Processing, &	Timeliness	0.40	26	Time to tactical warning	10 min	5-10 min	1 min	Seconds
	Dissemination	Security	0.10	27	Resistance to CM	None	Antijam	Antijam, antispoof	AJ, AS, antivirus
	0.18								

Appendix 1: Value Model

SPACECAST 2020 VALUE MODEL (Part 2)							Current	Minor	Significant	Order of
							Level	Improvement	Improvement	Magnitude
						Measure of Merit	(0.0)	(0.1)	(0.5)	(0.9)
		Acquisition & Tracking	Coverage	0.33	28	Covered area	--	Most of Eurasia	Half of globe	World
		0.25	Accuracy	0.33	29	Track accuracy	--	3 m in atmos.	3 m everywhere	1 m everywhere
			Discrimination	0.33	30	ID/Discrimination	--	Warning of RV/decoy	Limited discrimination	Mid-course discrimination
	Ballistic	Survivability	0.13		31	Qualitative judgn[illegible]t	--	No 1-point	Some capacity	Full capacity
	Missile							failures	concerted attack	major power attack
	Defense	Kill lethality	0.23		32	Pk	--	0.7 endoatmospheric	0.7 endo & boost	> 0.7 all phases
		Timeliness	0.14		33	Required warning time	--	10 days	Hours	Seconds
Force		Coverage	0.14		34	Defended area	--	--	Regional	Global
Application	0.37	Capacity	0.12		35	RVs handled at a time	--	A few	100	Entire enemy force
0.19		Acquisition & Tracking	Coverage	0.33	36	Covered area	--	Most of Eurasia	Half of globe	World
		0.20	Accuracy	0.33	37	Accuracy	--	3 m, unmoving tgt	3 m, large moving tgt	.1 m, ground or air tgt
	Air, Land, & Sea		Discrimination	0.33	38	ID/Discrimination	--	ID ground targets	Discr. mobile ground	Discr. ground/air decoys
	Defense from	Survivability	0.17		39	Qualitative judgment	--	No 1-point	Some capacity	Full capacity
	Space							failures	concerted attack	major power attack
		Kill lethality	0.13		40	Pk	--	0.9, fixed targets	0.5, armored vehicles	0.9, ground/air tgts
	0.27	Timeliness	0.23		41	Required warning time	--	Weeks	Days	Minutes
		Coverage	0.27		42	Covered area	--	--	Regional	Global
		Acquisition & Tracking	Coverage	0.33	43	Covered area	--	Most of Eurasia	Half of globe	World
		0.30	Accuracy	0.33	44	Accuracy	--	3 m, unmoving tgt	3 m, large moving tgt	1 m, ground or air tgt
	Power		Discrimination	0.33	45	ID/Discrimination	--	ID ground targets	Discr. mobile ground	Discr. ground/air decoys
	Projection	Survivability	0.13		46	Qualitative judgment	--	No 1-point	Some capacity	Full capacity
								failures	concerted attack	major power attack
	0.37	Kill lethality	0.17		47	Pk	--	0.9, fixed targets	0.5, armored vehicles	0.9, ground/air tgts
		Timeliness	0.22		48	Required warning time	--	10 days	Hours	Seconds
		Coverage	0.18		49	Covered area	--	--	Regional	Global

SPACECAST 2020 VALUE MODEL (Part 3)							Current	Minor	Significant	Order of
							Level	Improvement	Improvement	Magnitude
						Measure of Merit	(0.0)	(0.1)	(0.5)	(0.9)
	Surveillance	Availability	Coverage	0.20	50	Percent of space	90% Earth orbits	All Earth orbits	Cislunar space	Heliocentric orbits
		0.33	Revisit Time	0.80	51	Time to view	10s of hrs	1-6 hrs	10-60 min	< 1 min
		Robustness	Survivability	0.50	52	Qualitative judgment	Single-point	No 1-point	Some capacity	Full capacity
							failures	failures	concerted attack	major power attack
	0.33	0.33	Maintainability	0.50	53	Time to restore	Months +	Days	Hours	Seconds
		Accuracy	Resolution	0.25	54	Target sample distance	(classified)	1 m	10 cm	1cm
Space		0.33	Identification	0.25	55	Percent objects ID'd	(classified)	(classified)	85%	100%
Control			Track/Predict	0.50	56	Avg # objects lost	500	100	10	0
0.22	Protection	Active	Maneuver	0.30	57	Response time	Hours	1 hour	Minutes	Seconds
						Delta Velocity	m/sec	10 m/sec	100 m/sec	km/sec
		0.40	Jamming	0.30	58	Spectral range	Selected bands	Double # bands	All major bands	All RFs
			Decoys	0.30	59	Avg decoys / S/C	0	0.5	1	10
						Range of effectiveness	--	VIS	VIS+IR	VIS+IR+Radar
	0.33		Defensive Fire	0.10	60	Pk	--	0.1	0.2	0.7
		Passive	Redundancy	0.30	61	Qualitative judgment	Single-point	No 1-point	Some capacity	Full capacity
							failures	failures	concerted attack	major power attack
		0.60	CC&D	0.30	62	Pd	1	0.8	0.5	0.2
			Hardening	0.30	63	Sure safe W on target	1 W	10 W	100 W	1 MW
			Crypto Security	0.10	64	Percent S/C with crypto	90%	100%	--	--
	Negation	Target Acq			65	Time to produce state	Hours-days	2 hours	90 min	Minutes
		0.20				vector after launch				
		Destructive	Coverage	0.40	66	Percent of S/C	--	10%	20%	70%
	0.33	ASAT	Weapon Capacity	0.30	67	Avg # shots / target	--	0.1	1	10
		0.20	Effectiveness	0.30	68	Pk / shot	--	0.1	0.2	0.7
		Incapacitating	Coverage	0.60	69	Percent of systems	--	10%	20%	70%
		Systems	Effectiveness	0.40	70	Pr{incapacitate}	--	0.1	0.2	0.7
		0.60								

SPACECAST 2020 VALUE MODEL (Part 4)							Current	Minor	Significant	Order of
							Level	Improvement	Improvement	Magnitude
						Measure of Merit	(0.0)	(0.1)	(0.5)	(0.9)
		Cost	Recurring	0.50	71	Cost/lb to orbit	$6,500	$5,000	$2,000/lb	$200/lb
	Launch/Lift	0.25	Non-recurring	0.50	72	Develop/procure cost	$10B	$5B	$2B	$300M
	0.62	Responsiveness	Timeliness	0.17	73	Required warning time	Months	Weeks	Days	Hours
		0.20	Orbit range	0.17	74	Inclinations achievable	30%	40%	70%	90%
			Surge capability	0.17	75	Increase in rate	1 x	2 x	5 x	10 x
			Mission range	0.17	76	Missions supported	1	2	Several	All current
			Non-destruct abort	0.17	77	$Pr\{\text{soft abort} \mid \text{abort}\}$	0	0.1	0.5	0.9
Space			Post-abort restart	0.17	78	Time to restart ops	Years	Months	Weeks	Days
Support		Reliability	0.15		79	Pr{destructive abort}	5%	2-3%	1%	0.50%
0.22		Operability	Locations	0.20	80	# locations/orbit plane	1	2	5	10
		0.15	Fuel	0.20	81	Ease of handling	Cryogenic/toxic	Part non-cryo/toxic	Mostly non-cryo/toxic	All non-cryo/toxic
			Ease of handling	0.20	82	Percent blue-suit	0%	10%	50%	90%
			Launch ranges	0.20	83	Number and location	One coastal site	--	Many coastal sites	All CONUS
			Cmd & Control	0.20	84	Similarity to air ops	Current launch ops	Like Pegasus/Taurus	Further simplification	Like current air ops
		Environmental impacts	0.10		85	Toxicity and waste	High and much	Mostly dirty	Mostly clean	Clean, low waste
		Survivability	0.10		86	Type bases	Fixed/soft	Dispersed	Mobile/very dispersed	V. many/hardened/mobile
		Payload	0.05		87	Max lift/launch	50K	100K	200K	--
	Satellite	Communications	0.33		88	Link reliability	99.999%	--	99.9999%	99.99999%
	Control	Diagnosis	0.33		89	Avg time to diagnose	Hours	90 min	20 min	2 min
	0.20	Survivability	0.33		90	Type ground stations	Soft, worldwide	US territory	Mobile backups	Mainly mobile
		Sustainability	S/C--adaptability	0.13	91	HW failure recovery	Redundancy only	Ltd. reconfigurability	Major reconfigurability	Only minor mission losses
	Logistics of	0.40	S/C--upgradability	0.13	92	Design provisions	None	Limited	Major	Mission changes via S/W
	System		Grd--maintenance	0.13	93	Level of repairs rqd	Component	Board	LRU	S/W only
	0.18		Grd--maint. freq.	0.13	94	Frequency of actions	Daily	Monthly	Many months	Years
			Grd--maint. skills	0.13	95	Type of personnel	Contract specialist	Mix contract	High-skilled military	5-level
			Grd--parts	0.13	96	Type of piece parts rqd	Specialized	Mostly MIL-SPEC	MIL-SPEC	Off the shelf
			Grd--repair	0.13	97	% work value on site	100%	75%	50%	10%
			Grd--reliability	0.13	98	MTBF, critical parts	100% of system life	125% of system life	150% of system life	200% of system life
		Commonality	0.20		99	S/C commonality	System-specific	Modular subsystems	Reconfigure designs	Assemble at launch site
		Interoperability	0.20		100	S/C Interchangeability	None	Alternates available	Standard interface	S/C on any launcher
		Depots/Infrastructure	0.20		101	Dual-use technology	Ltd use, components	Expand use	Some dual-use designs	All systems dual-use

Appendix 1: Value Model

Value Hierarchy with "Rogue World" Weights					
					Line
OVERALL OBJECTIVE: Control and Exploit Space					Item
					No.
		Crisis availability	0.30		1
	Communications	Capacity	0.30		2
	0.20	Interoperability	0.10		3
		Security	0.30		4
		Availability	0.10		5
	Navigation &	Data availability	0.20		6
Force	Positioning	Accuracy	0.20		7
Enhance-	0.17	Robustness	0.50		8
ment		Processing Speed	0.27		9
	Intelligence &				10
0.31	Surveillance	ID Capability	0.27		11
	0.30	Coverage	0.07		12
		Day-night, All Weather	0.40		13
					14
	Environmental	Spectral Bands	0.20		15
	Monitoring and	Weather Prediction	0.20		16
	Control	Multispectral Coverage	0.20		17
		Weather Detail	0.20		18
	0.05	Weather Control	0.20		19
	Mapping,				20
	Charting, &	Surface Characterizatn	0.33		21
	Geodesy	Mensuration	0.33		22
	0.07	Data availability	0.33		23
		Coverage	0.20		24
	Warning,	ID Capability	0.20		25
	Processing, &	Timeliness	0.40		26
	Dissemination	Security	0.20		27
	0.22				

Appendix 2: Value Model Rogue World Weights

SPACECAST 2020 VALUE MODEL (Part 2)					Line
					Item
					No.
		Acquisition & Tracking	Coverage	0.33	28
		0.16	Accuracy	0.33	29
			Discrimination	0.33	30
	Ballistic	Survivability	0.25		31
	Missile				
	Defense	Kill lethality	0.17		32
		Timeliness	0.11		33
Force		Coverage	0.11		34
Application	0.43	Capacity	0.20		35
0.21		Acquisition & Tracking	Coverage	0.33	36
		0.13	Accuracy	0.33	37
	Air, Land, & Sea		Discrimination	0.33	38
	Defense from	Survivability	0.22		39
	Space				
		Kill lethality	0.17		40
	0.27	Timeliness	0.25		41
		Coverage	0.23		42
		Acquisition & Tracking	Coverage	0.33	43
		0.30	Accuracy	0.33	44
	Power		Discrimination	0.33	45
	Projection	Survivability	0.13		46
	0.30	Kill lethality	0.17		47
		Timeliness	0.23		48
		Coverage	0.17		49

Appendix 2: Value Model Rogue World Weights

SPACECAST 2020 VALUE MODEL (Part 3)					Line Item No.
	Surveillance	Availability	Coverage	0.20	50
		0.33	Revisit Time	0.80	51
		Robustness	Survivability	0.50	52
	0.33	0.33	Maintainability	0.50	53
		Accuracy	Resolution	0.25	54
Space		0.33	Identification	0.25	55
Control			Track/Predict	0.50	56
0.31	Protection	Active	Maneuver	**0.2**	57
		0.60	Jamming	**0.2**	58
			Decoys	**0.2**	59
	0.33		Defensive Fire	**0.4**	60
		Passive	Redundancy	0.30	61
		0.40	CC&D	0.30	62
			Hardening	0.30	63
			Crypto Security	0.10	64
	Negation	Target Acq			65
		0.20			
		Destructive	Coverage	0.40	66
	0.33	ASAT	Weapon Capacity	0.30	67
		0.60	Effectiveness	0.30	68
		Incapacitating	Coverage	0.60	69
		Systems	Effectiveness	0.40	70
		0.20			

Appendix 2: Value Model Rogue World Weights

SPACECAST 2020 VALUE MODEL (Part 4)					Line
					Item
					No.
		Cost	Recurring	0.50	71
	Launch/Lift	0.25	Non-recurring	0.50	72
	0.62	Responsiveness	Timeliness	0.17	73
		0.20	Orbit range	0.17	74
			Surge capability	0.17	75
			Mission range	0.17	76
			Non-destruct abort	0.17	77
Space			Post-abort restart	0.17	78
Support		Reliability	0.15		79
0.17		Operability	Locations	0.20	80
		0.15	Fuel	0.20	81
			Ease of handling	0.20	82
			Launch ranges	0.20	83
			Cmd & Control	0.20	84
		Environmental impacts	0.10		85
		Survivability	0.10		86
		Payload	0.05		87
	Satellite	Communications	0.33		88
	Control	Diagnosis	0.33		89
	0.20	Survivability	0.33		90
		Sustainability	S/C--adaptability	0.13	91
		0.40	S/C--upgradability	0.13	92
	Logistics		Grd--maintenance	0.13	93
	0.18		Grd--maint. freq.	0.13	94
			Grd--maint. skills	0.13	95
			Grd--parts	0.13	96
			Grd--repair	0.13	97
			Grd--reliability	0.13	98
		Commonality	0.20		99
		Interoperability	0.20		100
		Depots/Infrastructure	0.20		101

Appendix 2: Value Model Rogue World Weights

Appendix 3: White Paper System Descriptions

1. **Refueled Transatmospheric Vehicle** (TAV, nicknamed Black Horse)

(Spacelift: Suborbital, Earth to Orbit, and On Orbit)

This system provides spacelift and weapons deployment from the earth's surface to low earth orbit using a rocket-powered TAV that takes off from a runway like a conventional aircraft. The vehicle starts with a full load of propellant but minimal oxidizer. It flies up to rendezvous with a subsonic air refueling tanker to pick up a full load of oxidizer before continuing on to orbital altitude and speed.

2. **Orbit Transfer Vehicle** (OTV)

(Spacelift: Suborbital, Earth to Orbit, and On Orbit)

An unmanned autonomous boost vehicle used to transfer spacecraft between various orbits, primarily from low earth orbit (LEO) to higher orbits.

3. **Orbital Maneuvering Vehicle** (OMV)

(Spacelift: Suborbital, Earth to Orbit, and On Orbit)

An orbital propulsion and docking system used to take payloads from an earth to orbit lift vehicle and then place it in its final orbital plane or used to fetch and return orbiting payloads to a central repair and recovery location. The system would also be capable to carrying line replaceable units (LRUs) to a damaged/degraded satellite and accomplishing on-site repair or replacement.

4. **Space Modular System(s)**

(Space Modular Systems)

A satellite mother board concept in which the mission support equipment common to all satellites (power generation and distribution; communication transmitters, receivers, and antennas; navigation; computers and data storage; pointing/tracking/station keeping thruster; satellite tracking telemetry & control; cross link; etc.) is placed on-orbit and the separate mission specific payload packages are lifted to the mother board for integration with the common elements.

5. **Global Surveillance, Reconnaissance and Targeting System** (GSRT)

(Leveraging the infosphere: Surveillance and Reconnaissance in 2020)

An omni-sensorial collection, processing, and dissemination system to provide a real time information data base. This data base is used to create a virtual reality image of the area of interest. This virtual reality image is then used at all levels of command to provide situational awareness, technical and intelligence information, and two-way command and control.

6. **Super Global Positioning System** (S-GPS)

(Navigation and C3I for the 21st Century)

An advanced Global Positioning System that provides increased positioning accuracy on the order of centimeters, fusion with other sensor assets, enhanced on-board computational capabilities, and high data rate transmitter using low power and spread spectrum technology. S-GPS would employ a system of coded signals to provide multi-

level fused information and selectable accuracy's in order to deny capability to all but selected users.

7. **Space Traffic Control System** (SPATRACS)
(Space Traffic Control: The Culmination of Improved Space Operations)
Development of an integrated space traffic control system that will integrate sensor information (on and off board), provide collision avoidance information, and also deconflict flight planing. The system has a space segment consisting of a few small, simple satellites with passive sensors and on-board processing that are responsible for tracking all objects in space. The system also has a central ground facility that would provide fusion with other data from ground based sensor, validation, and additional analysis.

8. **Weather Forecast System**
(21st Century Weather Support Architecture)
Development and operational employment of an integrated weather information system consisting of on-orbit and ground sensors, and high speed information processing centers that produce data bases available to weather information users. These data bases would consist of observational weather data, forecast products, climatological information, and weather advisories and warning information.

9. **Space-Based Solar Monitoring and Alert Satellite System (SMASS)**
(Space-Based Solar Monitoring and Alert Satellite System)
A system of satellites to provide multispectral electro-optical imaging of the sun, sunspot mapping and analysis, interplanetary magnetic field mapping, solar flare monitoring/alert capability, plasma particle measurement, solar electromagnetic energy emissions in the extreme ultraviolet, and direct broadcast communication capability with space operation centers on earth and in space. Analysis and forecasting capability would exist on the sensor platforms as well as at the earth or space based operations center.

10. **Ionospheric Forecasting System**
(Space Weather Support for Communications)
A system of ground and space based sensors to monitor and map the earth's ionosphere. The system also includes a control facility to collect and process the data from the sensor network and then disseminate the information to the user community. The potential exists for ionospheric modification to enhance military missions.

11. **Holographic Projector**
(Projecting Information Power in War and Peace)
A system that could project holograms from space onto the ground, in the sky, or on the ocean anywhere in the theater of conflict for special operation deception missions. This system would be composed of either orbiting holographic projector or relay satellites that would pass data and instructions to a remotely piloted vehicle or aircraft that would then generate and project the holographic image.

12. **Space-Based High Energy Laser (HEL) System**
(Defensive Counterspace, Offensive Counterspace, and Force Application)
A space-based, multi-megawatt high energy laser system that can be used in several modes of operation. In its weapons mode with the laser at high power, it can attack ground, air, and space targets. In its surveillance mode, it can operate using the laser at low power levels for active illumination imaging or with the laser inoperative for passive imaging.

13. **Kinetic Energy Weapon (KEW) System**
(Defensive Counterspace, Offensive Counterspace, and Force Application)
A general class of weapons that include a variety of warhead types from flechettes and pellets to large and small heavy metal rods. They can be augmented with explosive or pyrotechnic devices but generally are not. They achieve their destructive effect by means of the hydrodynamic effect of penetrating the target at hypervelocity

14.. **High Powered Microwave System**
(Force Application)
A space based, high-power microwave weapon system that is capable of destroying ground, air, and space targets.

15. **Particle Beam Weapon System**
(Offensive Counterspace and Force Application)
A directed energy weapon system using a tightly focused, high-energy stream of electrically neutral atomic particles traveling near the speed of light. A space-based system to attack and disrupt targets in space or the edge of the atmosphere (BMD).

16. **Weather C3 System**
(Counterforce Weather Control)
A counterforce weather control system for military applications. The system consists of a global, on-demand weather observation system; a weather modeling capability; a space-based, directed energy weather modifier; and a command center with the necessary communication capabilities to observe, detect, and act on weather modification requirements.

17. **Solar Mirror System**
(Force Application)
A system of orbital mirrors to redirect solar energy for purposes of controlling terrestrial temperature and cloud patterns.

18. **Asteroid Detection System**
(Preparing for Planetary Defense)
An observation network composed of multispectral ground and space sensors for surveillance, detection, tracking, and characterization of space objects that may pose a threat if they were to collide with the earth. The system also includes a central facility to collect data from all the sensors in the network, maintain a current data base of all known objects, and disseminate collected information to appropriate authorities.

19. **Asteroid Negation System**

(Preparing for Planetary Defense)

A system that would be able to intercept any object that was determined to be a threat to the earth in sufficient time to deflect its course or fragment it into smaller pieces that do not pose a threat. Deflection and fragmentation could be accomplished be a variety of means from nuclear explosive devices, high specific impulse thrusters, kinetic energy projectiles, or directed energy devices.

Detailed Descriptions of Value Model Measures of Merit

Note: Detailed descriptions should be interpreted in the context of the position of the line in the value hierarchy. For instance, Line Item 1 is in Force Enhancement (Level 1), Communications (Level 2), Crisis availability (Level 3).

Force Enhancement Measures of Merit:

Line Item No.	Measure of Merit	Detailed Description
1	Initial # links in theater	Number of communication links available in theater at the outset of hostilities
2	Decompressed MB/sec	Capacity of each link in megabits per second, including benefits of data compression
3	Common-use systems	Degree to which all comsats can be used by all comm terminals
4	Level of secure links	Command level at which secure links are easily available
5	Crisis Availability	Degree to which nav signal is available in theater
6	Receiver size/cost	Size and cost of device that processes nav signal
7	Location precision	Expected error of navigation fix
8	Resistance to CM	Degree of resistance of common-user signal to countermeasures
9	Auto image processing	Amount of image interpretation that is done by machine
10	(not used)	
11	Image interpretability	Degree of detail that can be seen on an image
12	Area per unit time	Square miles that can be imaged per hour
13	% time data available	Average percent of a day during which an image can be taken of a given location
14	(not used)	
15	Multispectral bands	Number of spectral bands that can be collected at once
16	Prediction	Length of time over which a high-accuracy weather prediction is valid
17	Multispectral revisit time	Average time between viewing opportunities with a multispectral sensor
18	Instant WX info	Type of weather information available in near realtime
19	Amount of control	Available control over weather
20	(not used)	
21	Amount of detail	Type of detailed information available about surface and subsurface features
22	Geodetic precision	Precision with which locations are known
23	Time to get new map	Time required to produce and distribute a new map based on existing data
24	Coverage	Type of missiles that can be detected
25	What and where	What type of missile is being tracked and where it is headed
26	Time to tactical warning	Typical elapsed time until tactical user receives warning
27	Resistance to CM	Degree of resistance of spacecraft command and data signals to countermeasures

Force Application Measures of Merit:

Line	Measure of Merit	Description
28	Covered area	Portion of world covered by system acquisition and tracking subsystem
29	Track accuracy	Expected error in track; portion of world over which this is achieved
30	ID/Discrimination	Degree to which possible RVs can be identified and decoys discriminated from warheads
31	Qualitative judgment	Scorers' judgment on survivability of system
32	Pk	Probability of kill; portion of flight where this is attainable
33	Required warning time	Time required to bring the system to full alert
34	Defended area	Portion of world protected by system
35	RVs handled at a time	Number of re-entry vehicles that can be engaged at once
36	Covered area	Portion of world covered by system acquisition and tracking subsystem
37	Accuracy	Expected error in track; relevant type of target
38	ID/Discrimination	Degree to which possible targets can be identified and discriminated from decoys
39	Qualitative judgment	Scorers' judgment on survivability of system
40	Pk	Probability of kill for different terrestrial targets
41	Required warning time	Time required to bring the system to full alert
42	Covered area	Portion of world protected by system
43	Covered area	Portion of world covered by system acquisition and tracking subsystem
44	Accuracy	Expected error in track; relevant type of target
45	ID/Discrimination	Degree to which possible targets can be identified and discriminated from decoys
46	Qualitative judgment	Scorers' judgment on survivability of system
47	Pk	Probability of kill for different terrestrial targets
48	Required warning time	Time required to bring the system to full alert
49	Covered area	Portion of world protected by system

Space Control Measures of Merit:

Line	Measure of Merit	Description
50	Percent of space	Portion of space that is covered by surveillance system
51	Time to view	Maximum time until an object in orbit can be tracked
52	Qualitative judgment	Scorers' judgment on survivability of system
53	Time to restore	Time to restore full capability after a system failure
54	Target sample distance	Typical minimum resolved distance in image of spacecraft
55	Percent objects ID'd	Percent of possibly hostile spacecraft that are correctly identified
56	Avg # objects lost	Average daily number of space objects whose tracks have been lost
57	Response time	Time required to plan and execute an evasive maneuver
	Delta Velocity	Velocity change of feasible evasive maneuvers
58	Spectral range	Range of radio frequencies over which an attacker can be jammed
59	Avg decoys / S/C	Average number of decoys available per spacecraft
	Range of effectiveness	Range of sensors over which decoys are effective
60	Pk	Probability of kill of anti-ASAT weapon
61	Qualitative judgment	Scorers' judgment on survivability of system
62	Pd	Probability of detection
63	Sure safe W on target	Number of watts a spacecraft can receive without risk of damage
64	Percent S/C with crypto	Percent of spacecraft with encrypted uplinks and downlinks
65	Time to produce state vector after launch	Time from hostile spacecraft launch to possession of targeting-quality state vector
66	Percent of S/C	Percent of potentially hostile spacecraft that can be engaged
67	Avg # shots / target	Average number of times each potentially hostile spacecraft can be engaged
68	Pk / shot	Probability of kill for one engagement
69	Percent of systems	Percent of potentially hostile spacecraft that can
70	Pr{incapacitate}	Probability for one engagement that the target will be effectively incapacitated

Space Support Measures of Merit:

Line	Measure of Merit	Description
71	Cost/lb to orbit	Cost per pound to put spacecraft in low Earth orbit
72	Develop/procure cost	Cost to develop and procure a new launch system
73	Required warning time	Time required to prepare for and conduct a space launch
74	Inclinations achievable	Percent of all orbit inclination (0-110 degrees) that a launch system can achieve
75	Increase in rate	Possible increase in launch rate during crisis
76	Missions supported	Number of different spacecraft that a given booster can launch
77	Pr{soft abort|abort}	Probability that a post-liftoff launch abort will not harm the booster or payload
78	Time to restart ops	Time to restart launch operations after a major mishap
79	Pr{destructive abort}	Probability that a launch attempt will not be successful
80	# locations/orbit plane	Number of launch sites that can be used to launch into a given orbit plane
81	Ease of handling	The degree to which the booster's propellants are and/or toxic
82	Percent blue-suit	Percent of launch crew that is military personnel
83	Number and location	Number of location of launch ranges needed for space launches
84	Similarity to air ops	Degree to which launch operations resemble typical aircraft operations
85	Toxicity and waste	Toxicity and volume of vented propellants and combustion products
86	Type bases	Number and type (with regard to survivability) of available launch bases
87	Max lift/launch	Maximum payload to low Earth orbit per launch
88	Link reliability	Reliability of comm links in satellite control system
89	Avg time to diagnose	Average time to diagnose and correct a failure in satellite control system
90	Type ground stations	Number and type (with regard to survivability) of satellite control ground stations
91	HW failure recovery	Ability of spacecraft to adapt to hardware failures
92	Design provisions	Degree to which spacecraft can be upgraded
93	Level of repairs rqd	Typical hardware level at which repairs must be made
94	Frequency of actions	Typical frequency of maintenance actions
95	Type of personnel	Type of personnel required for maintenance
96	Type of piece parts rqd	Type of piece parts required
97	% work value on site	Percent of repair work value that is done on-site
98	MTBF, critical parts	Typical mean time between failure of critical parts
99	S/C commonality	Degree of commonality between spacecraft
100	S/C Interchangeability	Degree to which spacecraft can be launched on different boosters
101	Dual-use technology	Degree to which military and civil spacecraft use common designs

	TAV (#1)		OTV (#2)		OMV (#3)		Modular Sys. (#4)		GSRT (#5)		Super GPS (#6)	
Line	Sys Score:	34.1%	Sys Score:	14.8%	Sys Score:	3.6%	Sys Score:	3.1%	Sys Score:	18.9%	Sys Score:	4.7%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
1	80.0%	2.3%	40.0%	1.1%	30.0%	0.9%						
2												
3												
4												
5	10.0%	0.1%	5.0%	0.0%	10.0%	0.1%					10.0%	0.1%
6												
7											50.0%	0.9%
8											50.0%	1.5%
9									90.0%	3.0%		
10												
11									90.0%	1.8%	50.0%	1.0%
12	90.0%	1.2%	40.0%	0.5%					90.0%	1.2%		
13	90.0%	2.4%	40.0%	1.1%	30.0%	0.8%			90.0%	2.4%		
14												
15												
16												
17	50.0%	0.3%	10.0%	0.1%								
18												
19												
20												
21												
22											10.0%	0.1%
23	90.0%	1.0%										
24	80.0%	1.1%	40.0%	0.5%	30.0%	0.4%						
25												
26												
27												

Appendix 5: System Concept Scores

	SATRACS (#7)		WX Forecast (#8)		SMASS (#9)		Iono. Forecast (#10)		HEL (#12)	
Line	Sys Score:	3.6%	Sys Score:	4.3%	Sys Score:	0.8%	Sys Score:	0.8%	Sys Score:	32.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
1					10.0%	0.3%	10.0%	0.3%		
2							10.0%	0.3%		
3										
4										
5										
6										
7										
8										
9										
10										
11									90.0%	1.8%
12									90.0%	1.2%
13									90.0%	2.4%
14										
15			10.0%	0.1%						
16			10.0%	0.1%	90.0%	0.5%				
17			90.0%	0.5%						
18			10.0%	0.1%	10.0%	0.1%				
19										
20										
21										
22										
23										
24									50.0%	0.7%
25									50.0%	1.0%
26									50.0%	1.3%
27										

Appendix 5: System Concept Scores

	KEW (#13)		HPMW (#14)		Particle Beam (#15)		WX Control (#16)		Solar Mirrors (#17)		Ast. Det. (#18)	
Line	Sys Score:	12.2%	Sys Score:	14.7%	Sys Score:	10.9%	Sys Score:	2.3%	Sys Score:	0.5%	Sys Score:	2.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15							50.0%	0.3%				
16							90.0%	0.5%				
17							90.0%	0.5%				
18							90.0%	0.5%				
19							90.0%	0.5%	50.0%	0.3%		
20												
21												
22												
23												
24												
25												
26												
27												

Appendix 5: System Concept Scores

	TAV (#1)		OTV (#2)		OMV (#3)		Modular Sys. (#4)		GSRT (#5)		Super GPS (#6)	
Line	Sys Score:	34.1%	Sys Score:	14.8%	Sys Score:	3.6%	Sys Score:	3.1%	Sys Score:	18.9%	Sys Score:	4.7%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
28	90.0%	0.5%	40.0%	0.2%					90.0%	0.5%		
29									90.0%	0.5%		
30									90.0%	0.5%		
31	90.0%	0.8%	10.0%	0.1%								
32												
33												
34	90.0%	0.8%	40.0%	0.4%								
35	50.0%	0.4%										
36	90.0%	0.3%	40.0%	0.1%								
37											90.0%	0.3%
38												
39	90.0%	0.8%	10.0%	0.1%								
40											10.0%	0.1%
41												
42	90.0%	1.2%	40.0%	0.5%								
43	90.0%	0.6%	90.0%	0.6%					90.0%	0.6%		
44									90.0%	0.6%	90.0%	0.6%
45									90.0%	0.6%		
46	90.0%	0.8%	10.0%	0.1%								
47											10.0%	0.1%
48									90.0%	1.4%		
49	90.0%	1.1%	40.0%	0.5%					90.0%	1.1%		

Appendix 5: System Concept Scores

	SATRACS (#7)		WX Forecast (#8)		SMASS (#9)		Iono. Forecast (#10)		HEL (#12)	
Line	Sys Score:	3.6%	Sys Score:	4.3%	Sys Score:	0.8%	Sys Score:	0.8%	Sys Score:	32.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
28									90.0%	0.5%
29									90.0%	0.5%
30									90.0%	0.5%
31									90.0%	0.8%
32									90.0%	1.4%
33									80.0%	0.8%
34									90.0%	0.8%
35									50.0%	0.4%
36									90.0%	0.3%
37									50.0%	0.2%
38										
39									50.0%	0.4%
40									50.0%	0.3%
41									90.0%	1.0%
42									40.0%	0.5%
43									90.0%	0.6%
44									70.0%	0.5%
45										
46									90.0%	0.8%
47									40.0%	0.5%
48									90.0%	1.4%
49									50.0%	0.6%

Appendix 5: System Concept Scores

	KEW (#13)		HPMW (#14)		Particle Beam (#15)		WX Control (#16)		Solar Mirrors (#17)		Ast. Det. (#18)	
Line	Sys Score:	12.2%	Sys Score:	14.7%	Sys Score:	10.9%	Sys Score:	2.3%	Sys Score:	0.5%	Sys Score:	2.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
28	90.00%	0.52%			90.00%	0.52%						
29	90.00%	0.52%			50.00%	0.29%						
30	90.00%	0.52%			50.00%	0.29%						
31	50.00%	0.45%			50.00%	0.45%						
32	50.00%	0.80%			50.00%	0.80%						
33	70.00%	0.66%			90.00%	0.85%						
34	50.00%	0.47%			90.00%	0.85%						
35	50.00%	0.42%			50.00%	0.42%						
36	90.00%	0.30%	90.00%	0.30%								
37	50.00%	0.17%	10.00%	0.03%								
38												
39	50.00%	0.43%	50.00%	0.43%								
40	10.00%	0.07%	70.00%	0.46%								
41	60.00%	0.70%	90.00%	1.05%								
42	50.00%	0.68%	90.00%	1.23%								
43	90.00%	0.63%	90.00%	0.63%								
44	10.00%	0.07%	50.00%	0.35%								
45												
46	50.00%	0.45%	50.00%	0.45%								
47	10.00%	0.12%	70.00%	0.83%								
48	60.00%	0.91%	90.00%	1.36%								
49	70.00%	0.89%	90.00%	1.15%								

Appendix 5: System Concept Scores

	TAV (#1)		OTV (#2)		OMV (#3)		Modular Sys. (#4)		GSRT (#5)		Super GPS (#6)	
Line	Sys Score:	34.1%	Sys Score:	14.8%	Sys Score:	3.6%	Sys Score:	3.1%	Sys Score:	18.9%	Sys Score:	4.7%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
50	90.0%	0.4%	40.0%	0.2%					10.0%	0.0%		
51									90.0%	1.8%		
52	50.0%	0.6%	10.0%	0.1%					50.0%	0.6%		
53	50.0%	0.6%	10.0%	0.1%								
54									90.0%	0.6%		
55									90.0%	0.6%		
56									90.0%	1.1%		
57					20.0%	0.2%						
58												
59												
60												
61	50.0%	0.7%	10.0%	0.1%								
62												
63												
64												
65												
66	90.0%	0.5%	40.0%	0.2%								
67	50.0%	0.2%	10.0%	0.0%								
68												
69	90.0%	2.4%	40.0%	1.1%								
70												

Appendix 5: System Concept Scores

	SATRACS (#7)		WX Forecast (#8)		SMASS (#9)		Iono. Forecast (#10)		HEL (#12)	
Line	Sys Score:	3.6%	Sys Score:	4.3%	Sys Score:	0.8%	Sys Score:	0.8%	Sys Score:	32.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
50	10.0%	0.0%	10.0%	0.0%					50.0%	0.2%
51	90.0%	1.8%	90.0%	1.8%					60.0%	1.2%
52	50.0%	0.6%	50.0%	0.6%					70.0%	0.9%
53										
54	30.0%	0.2%	30.0%	0.2%					50.0%	0.3%
55	70.0%	0.4%	70.0%	0.4%					80.0%	0.5%
56	50.0%	0.6%	50.0%	0.6%					80.0%	1.0%
57										
58										
59										
60									90.0%	0.3%
61										
62										
63										
64										
65									70.0%	1.0%
66									90.0%	0.5%
67									90.0%	0.4%
68									90.0%	0.4%
69									90.0%	2.4%
70									90.0%	1.6%

	KEW (#13)		HPMW (#14)		Particle Beam (#15)		WX Control (#16)		Solar Mirrors (#17)		Ast. Det. (#18)	
Line	Sys Score:	12.2%	Sys Score:	14.7%	Sys Score:	10.9%	Sys Score:	2.3%	Sys Score:	0.5%	Sys Score:	2.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
50											90.0%	0.4%
51												
52												
53												
54											10.0%	0.1%
55											90.0%	0.6%
56											90.0%	1.1%
57												
58												
59												
60	50.0%	0.1%	90.0%	0.3%	90.0%	0.3%						
61			50.0%	0.7%	50.0%	0.7%						
62												
63												
64												
65	70.0%	1.0%										
66	70.0%	0.4%	90.0%	0.5%	90.0%	0.5%						
67	50.0%	0.2%	90.0%	0.4%	90.0%	0.4%						
68	90.0%	0.4%	90.0%	0.4%	90.0%	0.4%						
69			90.0%	2.4%	90.0%	2.4%						
70			90.0%	1.6%	90.0%	1.6%						

Appendix 5: System Concept Scores

	TAV (#1)		OTV (#2)		OMV (#3)		Modular Sys. (#4)		GSRT (#5)		Super GPS (#6)	
Line	Sys Score:	34.1%	Sys Score:	14.8%	Sys Score:	3.6%	Sys Score:	3.1%	Sys Score:	18.9%	Sys Score:	4.7%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
71	90.0%	1.5%	50.0%	0.9%								
72	60.0%	1.0%	50.0%	0.9%								
73	90.0%	0.4%	50.0%	0.2%								
74	50.0%	0.2%	50.0%	0.2%								
75	100.0%	0.5%										
76	70.0%	0.3%	70.0%	0.3%								
77	90.0%	0.4%	60.0%	0.3%								
78	50.0%	0.2%	20.0%	0.1%								
79	90.0%	1.8%	30.0%	0.6%								
80	100.0%	0.4%	30.0%	0.1%								
81	70.0%	0.3%	10.0%	0.0%								
82	90.0%	0.4%	90.0%	0.4%								
83	100.0%	0.4%										
84	90.0%	0.4%	50.0%	0.2%								
85	80.0%	1.1%	50.0%	0.7%								
86	50.0%	0.7%	50.0%	0.7%								
87			50.0%	0.3%								
88												
89							50.0%	0.7%				
90												
91	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%				
92	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	90.0%	0.2%				
93	50.0%	0.1%										
94												
95	70.0%	0.1%										
96	70.0%	0.1%										
97	70.0%	0.1%										
98												
99	90.0%	0.7%					90.0%	0.7%				
100	90.0%	0.7%			50.0%	0.4%	90.0%	0.7%				
101	90.0%	0.7%	90.0%	0.7%	90.0%	0.7%	90.0%	0.7%				

Appendix 5: System Concept Scores

	SATRACS (#7)		WX Forecast (#8)		SMASS (#9)		Iono. Forecast (#10)		HEL (#12)	
Line	Sys Score:	3.6%	Sys Score:	4.3%	Sys Score:	0.8%	Sys Score:	0.8%	Sys Score:	32.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
71										
72										
73										
74										
75										
76										
77										
78										
79										
80										
81										
82										
83										
84										
85										
86										
87										
88										
89										
90										
91							50.0%	0.1%	50.0%	0.1%
92							50.0%	0.1%	50.0%	0.1%
93										
94										
95										
96										
97										
98										
99										
100										
101										

Appendix 5: System Concept Scores

	KEW (#13)		HPMW (#14)		Particle Beam (#15)		WX Control (#16)		Solar Mirrors (#17)		Ast. Det. (#18)	
Line	Sys Score:	12.2%	Sys Score:	14.7%	Sys Score:	10.9%	Sys Score:	2.3%	Sys Score:	0.5%	Sys Score:	2.2%
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
71												
72												
73												
74												
75												
76												
77												
78												
79												
80												
81												
82												
83												
84												
85												
86												
87												
88												
89												
90												
91	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%		
92	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%	50.0%	0.1%		
93												
94												
95												
96												
97												
98												
99												
100												
101												

Appendix 5: System Concept Scores

Appendix 6: SPACECAST 2020 Critical Technologies

1. **Data Fusion** (MCTL 4.2.5): Data fusion is the technique whereby multivariate data from multiple sources are retrieved and processed as a single, unified entity. Data fusion is fundamental to command and control, with intelligence processing being a major ingredient. A significant set of a priori databases is crucial to the effective functioning of the fusion process.

2. **Electromagnetic Communications** (MCTL 5.1.1): This technology covers the development and production of a variety of telecommunication equipment used for electromagnetic transmission of information over any media. The information may be analog or digital, ranging in bandwidth from a single voice or data channel to video or multiplexed channels occupying hundreds of megahertz. Included are on-board satellite communication equipment and laser communication techniques capable of automatically acquiring and tracking signals and maintaining communications through atmospheric, exoatmospheric, and subsurface (water) media.

3. **Energetic Materials** (MCTL 12.7): This technology covers the development, production, and storage of constituent materials into composites or formulations that can be used as high energy propellants. This technology must be available if the ingredients of energetic formulations are to be manufactured safely in adequate quantity and quality for operational propulsion systems.

4. **Hard Real-Time Systems** (MCTL 4.2.4): Technologies required for the processing of data by a computer system that provides a required level of service as a function of available resources, within a guaranteed response time, regardless of the load on the system, when stimulated by an external event. Hard real-time operating systems that provide a shared set of computer resource management services designed and optimized for support of time-critical computer software applications, command and control, and aerospace vehicle navigation.

5. **High Energy Laser Systems** (MCTL 11.1): These technologies cover those required to generate high energy laser (HEL) beams (20 kW or greater average power, 1 kJ or more energy per pulse) at infrared, visible, or ultraviolet wavelengths and project them to a target where they will perform damage ranging from degradation to destruction. Included are those technologies covering HEL beam pointing, tracking control, beam propagation, and target coupling. Technologies required to integrate and implement a HEL system are also included.

6. **High Performance Computing** (MCTL 4.1.1): This technology covers the development of extremely high performance digital computers with vector and massive parallel processor architecture. This technology is required not only to process massive amounts of data in real time, but is also critical to the ability to computationally solve design problems in critical areas such as hypersonic aerodynamics, heat transfer, astrophysics, chemistry, and high energy physics.

7. **High Power Microwave Systems** (MCTL 11.2): This technology, also known as high power radio frequency systems technology, covers sources capable of generating sufficient high power microwave (HPMW) power, components for modulating the power, and antenna arrays which are required to direct the energy to a target. Peak powers of 100 megawatts or more, single pulse energy of 100J or more, and average powers of more than 10 kW are required for the development of weapons systems resulting in electrical component upset or burnout and antipersonnel applications.

8. **Image Processing** (MCTL 4.1.4): This technology is used for acquiring, transferring, analyzing, displaying and making use of image data in real time or near real time. Included are technologies related to implementation of mobile sensors for real time target acquisition and guidance, processing and displays of large complex data sets, data transmission and compression techniques, archival storage of imagery data, and real-time displays and three-dimensional presentation.

9. **Information Security** (MCTL 5.5): This technology includes the means and functions for controlling the accessibility or ensuring the confidentiality or integrity of information and communications, as well as the availability of resources. Included under this section are the development and production of equipment for information security functions, including measuring and test equipment, cryptographic material (including documents, devices, equipment and other apparatus), and software required or modified for the development, production, and use of this equipment.

10. **Kinetic Energy Systems** (MCTL 11.4): This technology is required to propel projectiles at velocities greater than 1.6 km/sec (much higher than conventional gun or rocket systems) to obtain an appropriate combination of properties such as shape, size, density and ductility at impact velocity. Technologies for precision pointing, tracking, launch and management of launch platforms are also included. Kinetic energy weapons are especially advantageous for the precision destruction of hard targets and armored vehicles, and the interception and mission denial of aircraft, space vehicles, and similar fast moving targets.

11. **Lasers** (MCTL 10.1): This technology covers the development and production of lasers at power levels described under MCTL 11.1, High Energy Laser Systems. Lasers consist of the laser hardware, the laser medium, mirrors and other optical components that form the laser oscillator cavity. Lasers may operate in a continuous, single-pulsed, or repetitively pulsed modes depending on the application and requirements. Energy sources (chemical or electrical) required to generate the HEL beam are included under this section.

12. **Liquid Rocket Propulsion** (MCTL 9.4.1): This technology covers liquid propulsion rocket systems that are used to power space launch vehicles to inject payloads into orbit and to change spacecraft orbits. Propellants for these systems include both storable and cryogenic types. The technologies of concern are those associated with the provision of more efficient propulsion through better propulsion control, lightweight motor hardware, and more efficient subsystems.

13. **Materials Technology** (MCTL 1.0): This technology includes multiapplication materials. Metals, alloys, and ceramics (MCTL 1.1) covers classes of metals and non-composite ceramics with enhanced strength and durability at progressively more severe load bearing and thermal environments. Composite materials (MCTL 1.2) covers high performance organic, metal, carbon, and ceramic matrix composites which result in structural weight reduction, enhanced range, propulsion, and vehicle capabilities to meet operational requirements. Carbon and ceramic composites may provide advanced thermal protection material for advanced aerospace vehicles.

14. **Micro-mechanical Devices** (MCTL 2.6): This technology covers the manufacture of micro mechanical devices, also known as micro machines, micro robots, and micro sensors, and their integration with microelectronics devices on a single "chip." Applications of this technology may include high precision mirrors and lenses for high output lasers, gyroscopic control guidance systems, sensors for control systems and miniature engines, accelerometers, transducers, and piezoelectric drives which can revolutionize military systems in terms of size, weight, and performance parameters such as power requirements.

15. **Navigation, Guidance, and Vehicle Control** (MCTL 7.0): These technologies are required for both autonomous and cooperative positioning (navigation), coordination, and control of military force elements. Included are technologies for flight management, vehicle guidance and control. Accurate positioning and control are essential for the effective coordination of highly mobile military flight vehicles. These capabilities also directly determine the delivery accuracy and lethality of "smart" weapons.

16. **Neutral Particle Beam (NPB) Systems** (MCTL 11.3.2): Technologies required for generation, propagation, and control of high-intensity atomic beams of hydrogen or its isotopes. Includes high current (tens of milliampere) negative hydrogen ion beam generation and acceleration, high burst power generation, beam control and monitoring subsystems, and target interaction and kill assessment. NPB weapons use projections from a high energy particle accelerator, through a charge neutralization cell, to a distant target. NPBs only have utility in space.

17. **Nonchemical High Specific Impulse Propulsion** (MCTL 9.5.2): This technology covers low-thrust, high specific impulse propulsion devices that can be used for spacecraft station keeping or orbit changes. Specifically, these propulsion systems include, but are not limited to, electrostatic, electrothermal, and electromagnetic systems, which utilize electric power to accelerate propellant gases to high exit velocities.

18. **Optics** (MCTL 10.2): This technology covers those required to develop and produce optics where the criticality of the component is major and the technology involved in the fabrication of key optical components involves techniques and processes which are not generally available in the commercial market. This technology, which includes adaptive optics, allows reconnaissance systems capable of operation without

atmospheric distortion and directed energy systems capable of diffraction-limited performance against space-based or endo-atmospheric targets.

19. **Power Systems and Energy Conversion** (MCTL 10.3.1): These technologies address the generation and delivery of power to meet electrical requirements under specified environmental conditions, and within specific size and weight constraints. These technologies include low power AC and DC power generation for sensitive electronics applications, space-qualified field generation equipment, high energy density systems, energy conversion technologies applied to generation of primary electrical power, techniques for continuous conversion/power generation, and pulse power applications.

20. **Pulsed Power Systems** (MCTL 10.3.3): These technologies cover the development and production of equipment required for moderate and high pulse power systems (greater than 2 megawatts average power with more than 10 kJ per pulse). Included are pulse power subsystems required for active radar and directed energy systems. These technologies address high power solid state control components, switches, and techniques for achieving and preserving fine-grained pulse characteristics in moderate and high power systems.

21. **Robotics, Controllers, and End-Effectors** (MCTL 2.2.5): This technology covers multifunctional manipulation devices employing feedback information from one or more sensors to orient parts, tools, or other devices through variable movements in three-dimensional space. In order to perform complex, high precision tasks, they contain at least three open or closed loop servo devices and have accessible programmability by means of off-line computer or programmable logic controllers.

22. **Sensors** (MCTL 6.0): These technologies include all sensor types that are of military interest. Included are technologies for acoustics, optical sensors, cameras, radar identification, gravity meters, magnetometers, and associated gradiometers. Critical elements include specially developed materials and precision manufacture, integration of the components with processing subsystems, simulation and modeling, and thorough testing for performance and operational robustness.

23. **Spacecraft Structures** (MCTL 9.5.1): These technologies cover the development and production of dimensionally stable structures for spacecraft which employ techniques for control of structural distortion, including materials designed for zero coefficient of thermal expansion designs to prevent structural outgassing in orbit, and materials that provide high strength and high stiffness. Also included are as analysis techniques used to simulate the dynamic interaction of the structure with the spacecraft control system and to provide the means to define a design with the required stability characteristics for precision structures such as optical systems and antennas or with large flexible appendages such as solar panels. This section also covers sensors and actuators used for spacecraft vibration control.

24. **Vehicle Survivability** (MCTL 9.7): These technologies enhance the survivability of U.S. aerospace vehicles to threats of detection and attack by enemy forces. Included under this category are signature-control for avoiding or delaying detection and other measures such as maneuverability or high speed to reduce engagement opportunity after detection has occurred. Vehicle survivability is achieved or enhanced by denying the enemy the ability to "see" the vehicle through visual, radar, radiated heat and noise signatures or communications signals.

25. **Virtual Reality**: Virtual reality technologies are actually a combination of those encompassed by Dynamic Training and Simulation (MCTL 4.1.2), Image Processing (MCTL 4.1.4), and Hard Real-Time Systems (MCTL 4.2.4). Dynamic Training and Simulation covers techniques that allow operator feedback into real time control functions that enhance realism by coordinated multisensor operator inputs. Hard Real-Time Systems involve the processing of data by a computer system providing a required level of service, as a function of available resources, within a guaranteed response time when stimulated by an external event. These technologies enable a human to efficiently operate complex systems from a remote location or "project" himself into an artificial environment for purposes such as command and control.

Judgments on Percentage Dependance of Each System on Each Critical Technology

Technology (see Appendix 6 for descriptions):

	System	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17	#18	#19	#20	#21	#22	#23	#24	#25	Sum
1	TAV			10			20							30	5	10						20			5		100
2	OTV													5	20			40		20		15					100
3	OMV						10								20			20		15		25				10	100
4	Mod Sys																	15				20		45		20	100
5	GSRT	20	10				20		15						10								25				100
6	S-GPS	20					20			15					15	20				5			5				100
7	SPATRACS		30		10		30																30				100
8	WX F'cast	55					35		10																		100
9	SMASS	20	10				25		15														30				100
10	Iono. F'cast	10			45		15																30				100
11	Holo. Proj.		5			15	10		20			10							20	20							100
12	HEL					25	5					25			5	5			25	10							100
13	KEW						20				40				15	25											100
14	HPMW						5	45							5	5					40						100
15	PB						5								5	5	45				40						100
16	WX C3	10	10		15		50																15				100
17	Mirror															25			25					50			100
18	Ast. Det	5			10		15												20				50				100
19	Ast. Neg															35		65									100

Appendix 7: Contributions of Technologies to Systems

Appendix 8: Spacelift Vehicle Descriptions

Delta II 7925

Developed from the Thor IRBM and Vanguard upper stages in 1959 by the Douglas Aircraft Company, the Delta II uses a single RS-27 single-start liquid bi-propellant (liquid oxygen - kerosene) engine producing 210k lbs of thrust at sea level with two Rocketdyne verniers providing roll control. A cluster of solid rocket strap-ons around the base of the first stage can be added for additional launch thrust. The 7925 version of Delta II can deliver approximately 11,000 lbs to a 200 NM LEO (28.7°). Cape Canaveral, with its two Delta launch pads, is the only currently active launch complex. Vehicle integration and checkout typically takes place at the Cape over a 16 week period prior to launch (eight weeks vertical stack time). Cost to commercial users is about $50M per launch at 1990 rates.

Production was closed down in 1984, but the Shuttle failure in January 1986 resulted in production re-activation. In January 1987, the Air Force awarded a production contract for the Delta II as the Medium Launch Vehicle to launch the network of GPS Navstar satellites after that requirement had been off-loaded from the Shuttle.

ZENIT

The Russian SL-16 (Zenit) began flight testing with a sub-orbital flight on 13 April 1985. It is the first new Russian launcher developed since 1972. The first stage of the Zenit booster is the Energia strap-on (SL-17). There is a two stage version (Zenit 2) and a three stage version (Zenit 3). The Zenit uses four RD-170 gimbaled rocket motors burning liquid oxygen and kerosene producing 1.63 million pounds of thrust at sea level. The second stage uses a single RD-120 fixed re-ignitable engine producing 186.5k lbs of thrust. Zenit 2 is capable of placing an encapsulated payload canister with a standardized interface weighing 30,000 lbs into a 100 NM LEO (51.6°) from the Tyuratam space port. Payload volume is $90m^3$ for the 13.65m long shroud.

Zenit is assembled horizontally, with the payload integrated on stage 2 before stage 1/2 mating. Assembly of the vehicle alone requires 80 hours increasing to 116 hours with the payload. Transfer to one of two pads is by rail; erection and launch processing highly automated, requiring 21-80 hr between initial integration and launch.

The Soviets began discussions for a cooperative launch arrangement with the Australian government in 1986. The program would offer equatorial launches from the Cape York Space Port to be constructed at Queensland on the northern Australian coast. The Australians intend to purchase and launch Zenit boosters using local launch crews trained initially by the Soviets. A similar licensing agreement between the U.S. and Russia should be possible to establish launch capabilities for the Zenit booster from Cape Canaveral and Vandenberg AFB. A follow-on manufacturing arrangement might also be possible. A cooperative technology enhancement program between the two countries to use aluminum-lithium and carbon-carbon composites in place to the titanium in manufacture of Zenit could result in a lighter weight booster that is less expensive to make and can place more payload in orbit.

BLACK HORSE

In-flight oxidizer transfer to a rocket-powered Transatmospheric Vehicle permits the Black Horse to achieve orbit with relatively low weight compared to a fully loaded flight vehicle using a horizontal take off from a runway. The weight of many key components, such as wings and landing gear, is substantially reduced because of the lower gross take off weight. This manned vehicle takes off like a conventional aircraft under rocket power from two of its seven engines, using jet fuel (JP-5) and a non-cryogenic oxidizer hydrogen peroxide. After rendezvous with and oxidizer transfer from a tanker aircraft, the vehicle ignites all seven of its engines, accelerates to high speed, and pulls up into a steady climb into orbit. An estimated 5,000 lbs could be carried to a 100 NM LEO in an encapsulated payload canister with a standardized interface. Non-cryogenic, non-toxic propellants permit the propellant transfer to use existing tankers, and a small aircraft similar in size to an F-16 could demonstrate the capability and achieve orbit. The concept is sufficiently simple that relatively little in the way of new facilities or support equipment is required.

DELTA CLIPPER

Delta Clipper is a Single Stage to Orbit (SSTO) fully reusable, vertical take-off and landing, launch vehicle making use of a simplified launch infrastructure (clean pad) to lower launch costs. The vehicle has a gross lift-off weight of approximately 1.4 million pounds and can carry about 10,000 lbs to a 100 NM LEO in an encapsulated payload canister with a standardized interface. The vehicle uses a ballistic trajectory to achieve and return from orbit, with rocket power providing the control for landing. It is propelled by cryogenic rocket motors using liquid oxygen and liquid hydrogen. The vehicle is not normally manned. An upcoming third test flight of a subscale, proof of concept vehicle, is reportedly to confirm the ability to invert from reentry attitude to landing attitude.

NASP Derived Vehicle (Scram-jet/Rocket SSTO)

A horizontal takeoff and landing single-stage-to-orbit (SSTO) vehicle powered by a hydrogen-fueled propulsion system that integrates ramjet/scramjet engines with small rocket motors for sustained cruise at Mach 5-15 in the atmosphere and a Mach 25 orbital capability. The vehicle would use a combination of engines. A conventional jet for slow speed, with ramjets taking over to carry the craft up to about Mach 6 at which point the scramjets using slush hydrogen for fuel would take it to near orbital velocity. Small rocket motors would provide the final push to orbit. Gross take off weight is estimated at 917,000 lbs. This vehicle is capable of carrying a 25,000 lb encapsulated payload canister with a standardized interface. This equates to a payload mass fraction of 26%. Because of its weight and take-off speed requirement, this vehicle would operate from large airfields with long runways such as those at SAC bomber bases and commercial airfield rated to handle Boeing 747 jumbo jets.

Two-Stage-To-Orbit (TSTO)

A design for a small two-stage-to-orbit (TSTO) system that would take maximum advantage of off-the-shelf systems. Using a 747-class carrier aircraft, a small launch vehicle could be deployed at subsonic speeds and moderate altitude (40,000 ft). The advantage gained by the initial velocity and altitude of the carrier aircraft, combined with the reduced drag and improved engine performance (rocket engine performance is altitude dependent) would make this feasible with today's fuels and materials. The spacecraft would be a lifting-body design, to allow efficient energy management on return from orbit and a safe abort mode. The vehicle would use an unpowered Space Shuttle like glide de-orbit, return, and horizontal landing on a conventional runway. The orbital vehicle would have gross weight including fuel of approximately 150,000 lbs. This is a similar weight to the shuttle Enterprise that was carried and dropped from a 747 for aerodynamic control and landing tests. The rocket engines would be fueled by liquid oxygen and slush hydrogen. The craft would be designed to carry a 5,000 lb encapsulated payload canister with a standardized interface. Advantages of a TSTO approach include being able to launch from almost any airport, worldwide, with the addition of equipment to fuel the spacecraft and lift it onto the carrier aircraft. The carrier aircraft could fly to any location within its range to launch the spacecraft into the proper orbit. Launching over lightly populated areas or the oceans would reduce safety problems and eliminate noise problems associated with supersonic flow. Launch from altitude, as opposed to horizontal takeoff from the ground, would reduce the size of the wings on the spacecraft considerably, thereby reducing weight of the reentry protection system and overall spacecraft.

	Delta		Zenit		TAV		DC		NASP		TSTO	
Line	Sys. Score:	0.04271	Sys. Score:	0.09957	Sys. Score:	0.34106	Sys. Score:	0.32869	Sys. Score:	0.32123	Sys. Score:	0.33728
Item No.	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
1			30.00%	0.85%	80.00%	2.28%	80.00%	2.28%	80.00%	2.28%	80.00%	2.28%
2												
3												
4												
5			10.00%	0.07%	10.00%	0.07%	10.00%	0.07%	10.00%	0.07%	10.00%	0.07%
6												
7												
8												
9												
10												
11												
12			10.00%	0.13%	90.00%	1.19%	90.00%	1.19%	90.00%	1.19%	90.00%	1.19%
13			10.00%	0.26%	90.00%	2.38%	90.00%	2.38%	90.00%	2.38%	90.00%	2.38%
14												
15												
16												
17			10.00%	0.05%	50.00%	0.26%	50.00%	0.26%	50.00%	0.26%	50.00%	0.26%
18												
19												
20												
21												
22												
23			10.00%	0.11%	90.00%	1.00%	90.00%	1.00%	90.00%	1.00%	90.00%	1.00%
24			20.00%	0.27%	80.00%	1.07%	80.00%	1.07%	80.00%	1.07%	80.00%	1.07%
25												
26												
27												

Appendix 9: Launch System Scoring Data

	Delta		Zenit		TAV		DC		NASP		TSTO	
Line	Sys. Score:	0.04271	Sys. Score:	0.09957	Sys. Score:	0.34106	Sys. Score:	0.32869	Sys. Score:	0.32123	Sys. Score:	0.33728
Item	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted	Line Item	Weighted
No.	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score	Score	Line Score
28			10.00%	0.06%	90.00%	0.52%	90.00%	0.52%	90.00%	0.52%	90.00%	0.52%
29												
30												
31					90.00%	0.82%	90.00%	0.82%	90.00%	0.82%	90.00%	0.82%
32												
33												
34					90.00%	0.85%	90.00%	0.85%	90.00%	0.85%	90.00%	0.85%
35					50.00%	0.42%	50.00%	0.42%	50.00%	0.42%	50.00%	0.42%
36			10.00%	0.03%	90.00%	0.30%	90.00%	0.30%	90.00%	0.30%	90.00%	0.30%
37												
38												
39					90.00%	0.78%	90.00%	0.78%	90.00%	0.78%	90.00%	0.78%
40												
41												
42					90.00%	1.23%	90.00%	1.23%	90.00%	1.23%	90.00%	1.23%
43					90.00%	0.63%	90.00%	0.63%	90.00%	0.63%	90.00%	0.63%
44												
45												
46					90.00%	0.82%	90.00%	0.82%	90.00%	0.82%	90.00%	0.82%
47												
48												
49					90.00%	1.15%	90.00%	1.15%	90.00%	1.15%	90.00%	1.15%

Appendix 9: Launch System Scoring Data

	Delta		Zenit		TAV		DC		NASP		TSTO	
Line	Sys. Score:	0.04271	Sys. Score:	0.09957	Sys. Score:	0.34106	Sys. Score:	0.32869	Sys. Score:	0.32123	Sys. Score:	0.33728
Item No.	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
50					90.00%	0.44%	90.00%	0.44%	90.00%	0.44%	90.00%	0.44%
51												
52			10.00%	0.12%	50.00%	0.61%	50.00%	0.61%	50.00%	0.61%	50.00%	0.61%
53			10.00%	0.12%	50.00%	0.61%	50.00%	0.61%	50.00%	0.61%	50.00%	0.61%
54												
55												
56												
57												
58												
59												
60												
61					50.00%	0.66%	50.00%	0.66%	50.00%	0.66%	50.00%	0.66%
62												
63												
64												
65												
66					90.00%	0.53%	90.00%	0.53%	90.00%	0.53%	90.00%	0.53%
67					50.00%	0.22%	50.00%	0.22%	90.00%	0.40%	50.00%	0.22%
68												
69			10.00%	0.26%	90.00%	2.38%	90.00%	2.38%	90.00%	2.38%	90.00%	2.38%
70												

Appendix 9: Launch System Scoring Data

	Delta		Zenit		TAV		DC		NASP		TSTO	
Line	Sys. Score:	0.04271	Sys. Score:	0.09957	Sys. Score:	0.34106	Sys. Score:	0.32869	Sys. Score:	0.32123	Sys. Score:	0.33728
Item No.	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
71			50.00%	0.85%	90.00%	1.53%	70.00%	1.19%	60.00%	1.02%	90.00%	1.53%
72	70.00%	1.19%	90.00%	1.53%	60.00%	1.02%	60.00%	1.02%	20.00%	0.34%	60.00%	1.02%
73			50.00%	0.23%	90.00%	0.41%	70.00%	0.32%	70.00%	0.32%	70.00%	0.32%
74			10.00%	0.05%	50.00%	0.23%	40.00%	0.18%	60.00%	0.27%	50.00%	0.23%
75			10.00%	0.05%	100.00%	0.45%	100.00%	0.45%	100.00%	0.45%	100.00%	0.45%
76	10.00%	0.05%	70.00%	0.32%	70.00%	0.32%	70.00%	0.32%	70.00%	0.32%	70.00%	0.32%
77					90.00%	0.41%	10.00%	0.05%	90.00%	0.41%	90.00%	0.41%
78			30.00%	0.14%	50.00%	0.23%	50.00%	0.23%	50.00%	0.23%	50.00%	0.23%
79	90.00%	1.84%	50.00%	1.02%	90.00%	1.84%	90.00%	1.84%	90.00%	1.84%	90.00%	1.84%
80					100.00%	0.41%	50.00%	0.20%	100.00%	0.41%	100.00%	0.41%
81					70.00%	0.29%			10.00%	0.04%		
82			90.00%	0.37%	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%
83					100.00%	0.41%	90.00%	0.37%	90.00%	0.37%	100.00%	0.41%
84					90.00%	0.37%	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%
85	80.00%	1.09%	80.00%	1.09%	80.00%	1.09%	90.00%	1.23%	80.00%	1.09%	80.00%	1.09%
86					50.00%	0.68%	50.00%	0.68%	50.00%	0.68%	50.00%	0.68%
87												
88												
89												
90												
91					50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
92			50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
93	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
94												
95			50.00%	0.10%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
96			50.00%	0.10%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
97			30.00%	0.06%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
98												
99			90.00%	0.71%	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%
100			50.00%	0.40%	90.00%	0.71%	90.00%	0.71%	10.00%	0.08%	90.00%	0.71%
101			50.00%	0.40%	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%

Appendix 9: Launch System Scoring Data

	TAV (#1)		TAV + OTV (#2)		TAV + OTV + Mod. Sys. (#4)	
Line	System Score:	0.34106	System Score:	0.36761	System Score:	0.37653
Item No.	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
1	80.00%	2.28%	90.00%	2.56%	90.00%	2.56%
2						
3						
4						
5	10.00%	0.07%	20.00%	0.15%	20.00%	0.15%
6						
7						
8						
9						
10						
11						
12	90.00%	1.19%	95.00%	1.26%	95.00%	1.26%
13	90.00%	2.38%	95.00%	2.51%	95.00%	2.51%
14						
15						
16						
17	50.00%	0.26%	70.00%	0.36%	70.00%	0.36%
18						
19						
20						
21						
22						
23	90.00%	1.00%	90.00%	1.00%	90.00%	1.00%
24	80.00%	1.07%	95.00%	1.27%	95.00%	1.27%
25						
26						
27						

Appendix 10: Scoring Data for Combined Spacelift Systems

Line	TAV (#1)		TAV + OTV (#2)		TAV + OTV + Mod. Sys. (#4)	
Item No.	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
28	90.00%	0.52%	95.00%	0.55%	95.00%	0.55%
29						
30						
31	90.00%	0.82%	95.00%	0.86%	95.00%	0.86%
32						
33						
34	90.00%	0.85%	95.00%	0.89%	95.00%	0.89%
35	50.00%	0.42%	50.00%	0.42%	50.00%	0.42%
36	90.00%	0.30%	95.00%	0.32%	95.00%	0.32%
37						
38						
39	90.00%	0.78%	95.00%	0.82%	95.00%	0.82%
40						
41						
42	90.00%	1.23%	95.00%	1.30%	95.00%	1.30%
43	90.00%	0.63%	90.00%	0.63%	90.00%	0.63%
44						
45						
46	90.00%	0.82%	95.00%	0.86%	95.00%	0.86%
47						
48						
49	90.00%	1.15%	95.00%	1.21%	95.00%	1.21%

Appendix 10: Scoring Data for Combined Spacelift Systems

Line Item No.	TAV (#1) Line Item Score	TAV (#1) Weighted Line Score	TAV + OTV (#2) Line Item Score	TAV + OTV (#2) Weighted Line Score	TAV + OTV + Mod. Sys. (#4) Line Item Score	TAV + OTV + Mod. Sys. (#4) Weighted Line Score
50	90.00%	0.44%	95.00%	0.46%	95.00%	0.46%
51						
52	50.00%	0.61%	70.00%	0.86%	70.00%	0.86%
53	50.00%	0.61%	70.00%	0.86%	70.00%	0.86%
54						
55						
56						
57						
58						
59						
60						
61	50.00%	0.66%	60.00%	0.79%	60.00%	0.79%
62						
63						
64						
65						
66	90.00%	0.53%	95.00%	0.56%	95.00%	0.56%
67	50.00%	0.22%	60.00%	0.26%	60.00%	0.26%
68						
69	90.00%	2.38%	95.00%	2.51%	95.00%	2.51%
70						

Appendix 10: Scoring Data for Combined Spacelift Systems

Line	TAV (#1)		TAV + OTV (#2)		TAV + OTV + Mod. Sys. (#4)	
Item No.	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score	Line Item Score	Weighted Line Score
71	90.00%	1.53%	95.00%	1.62%	95.00%	1.62%
72	60.00%	1.02%	60.00%	1.02%	60.00%	1.02%
73	90.00%	0.41%	95.00%	0.43%	95.00%	0.43%
74	50.00%	0.23%	60.00%	0.27%	60.00%	0.27%
75	100.00%	0.45%	100.00%	0.45%	100.00%	0.45%
76	70.00%	0.32%	90.00%	0.41%	90.00%	0.41%
77	90.00%	0.41%	90.00%	0.41%	90.00%	0.41%
78	50.00%	0.23%	50.00%	0.23%	50.00%	0.23%
79	90.00%	1.84%	90.00%	1.84%	90.00%	1.84%
80	100.00%	0.41%	100.00%	0.41%	100.00%	0.41%
81	70.00%	0.29%	70.00%	0.29%	70.00%	0.29%
82	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%
83	100.00%	0.41%	100.00%	0.41%	100.00%	0.41%
84	90.00%	0.37%	90.00%	0.37%	90.00%	0.37%
85	80.00%	1.09%	80.00%	1.09%	80.00%	1.09%
86	50.00%	0.68%	50.00%	0.68%	50.00%	0.68%
87			50.00%	0.34%	50.00%	0.34%
88						
89					50.00%	0.73%
90						
91	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
92	50.00%	0.10%	50.00%	0.10%	90.00%	0.18%
93	50.00%	0.10%	50.00%	0.10%	50.00%	0.10%
94						
95	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
96	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
97	70.00%	0.14%	70.00%	0.14%	70.00%	0.14%
98						
99	90.00%	0.71%	90.00%	0.71%	95.00%	0.75%
100	90.00%	0.71%	90.00%	0.71%	95.00%	0.75%
101	90.00%	0.71%	90.00%	0.71%	90.00%	0.71%

Appendix 10: Scoring Data for Combined Spacelift Systems

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(Study Chair)

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GLOSSARY

ACES. Autocalibrating Extreme Ultraviolet Spectrometers developed by Phillips Laboratory

ADSID. Air-Delivered Seismic Detection

AF. Air Force

AFDIS. AFGWC Dial-In System for weather product support

AFGWC. Air Force Global Weather Center, Offutt AFB NE

AFMC. Air Force Materiel Command

AFSPC. New acronym for Air Force Space Command

Amor asteroid. Asteroid having perihelion distance between 1.017 and 1.3 astronomical units (AU).

aperture. The diameter of the primary lens or mirror of a telescope; hence, the best single measure of the light-gathering power of a telescope.

aphelion. The point in elliptical orbit of a planet, asteroid, or comet that is farthest from the Sun.

Apollo asteroid. Asteroid having orbital parameters similar to the Earth's.

ARPA. Advanced Research Projects Agency

Artificial intelligence. A generic term commonly used to indicate the inclusion in software of some type of automated application of rules, the results of which give the appearance of "intelligence" on the part of the computer. An example would be a computer which uses language rules to carry on a conversation with the human using the computer.

ASAT. Anti-Satellite

ASCM. Advanced Spaceborne Computer Module

asteroid. An object orbiting the Sun that is smaller than a major planet (tens of meters to about 1,000 km diameter), but shows no evidence of an atmosphere or other types of activity associated with comets. Most asteroids are located in a belt between Mars and Jupiter from 2.2 to 3.3 AU from the Sun.

astronomical unit (AU). Average distance between the Earth and Sun, equal to about 150 million kilometers.

Aten asteroid. Asteroid having semimajor axis less than 1.0 AU and aphelion distance greater than 0.983 AU.

ATLAS. Aerospace Traffic Location and Sensing

ATN. NOAA's Advanced TIROS-N satellite

ATSSB. Advanced Technology Standard Satellite Bus

Automated assistants. Any of several software tools which can be programmed to automatically find and/or process information according to rules or guidelines given by a specific user of the resultant information. For example, tell an automated assistant to check all the news service articles for the last two months, and report tomorrow at 0800 with all articles which mentioned both Bosnia and any type of US military forces.

AWACS. Airborne Warning and Control System

AWDS. Automated Weather Distribution System; Air Force weather communications and data processing/analysis system used in base weather support

AWN. Automated Weather Network; Air Force high-speed weather data communications network

BDA. Battle Damage Assessment

BMDO. Ballistic Missile Defense Office

bolide. An asteroid or meteor which explodes in the Earth's atmosphere.

Bulletin board. Used in this paper to indicate the on-line (electronic) bulletin boards, where users of the board post notices using modems or network connections such as Internet. Users also read notices and carry out other bulletin board business, such as multiparty on-line conversations where each party types in comments in an ongoing discussion.

C3BM. Command, Control, and Communications and Battle Management

C4I. Command, Control, Communications, Computers and Intelligence

C6I. Command, Control, Communications, Computers and Beyond

CAD. Computer Aided Design

CAT. Computerized Axial Tomography

CC&D. Concealment, Camouflage and Deception

CCD. Charge-Coupled Device. A solid-state detector used for low-light imaging.

chromosphere. Middle solar atmosphere layer defined to begin at the temperature minimum in the solar atmosphere of 4300 degrees Kelvin, extends approximately 3000 km; region where solar flares are observed.

CICBM. Conventional Intercontinental Ballistic Missile

CINC. Commander in Chief

CINCSAT. Commander in Chief Satellite

comet. A volatile-rich body that develops a transient atmosphere as it orbits the Sun. The orbit is usually highly elliptical or even parabolic (average perihelion distance less than 1 AU; average aphelion distance, roughly 10^4 AU). When a comet comes near the Sun, some of its material vaporizes, forming a large head of tenuous gas, and often a tail formed by the solar wind.

COMSEC. Communications Security

CONUS. Continental United States

Corona. Very hot, tenuous, outer layer of the solar atmosphere, fully ionized, affected by the solar magnetic field, region from which solar wind is emitted

Counterforce operations. those space or trans-atmospheric activities aimed at opposing or defending against threatening force anywhere on the planet or in the region of space. Although counterforce activities are defensive in intent, they do not preclude defense by offensive action. Counterforce activities include the use of information and weather as weapons. They also include defense against non-human threats to the vitality and security of the United States and the people on the planet.

CRAF. Civil Reserve Air Fleet

CSLBM. Conventional Submarine Launched Ballistic Missile

CSOC. Consolidated Space Operations Center

CSTC. Consolidated Space Test Center

D. Fractal Dimension

DEW. Directed Energy Weapons

DFCB. Data Fusion Control Bank

DMSP. Defense Meteorological Satellite Program

DNA. Deoxyribonucleic Acid

DOS. Disk Operating System

DSCS. Defense Satellite Communications System

DSP. Defense Support Program

ECA. Earth-Crossing-Asteroid. An asteroid whose orbit crosses the Earth's orbit or will at some time cross the Earth's orbit as it evolves under the influence of perturbations from Jupiter and the other planets.

eccentricity. The measure of the degree to which an ellipse is not circular; ratio of the distance between the foci to the major axis.

ECM. Electronic Countermeasures

Electronic performance support system. A general grouping of software tools to aid productivity. A typical group might include an electronic phone book/rolodex, electronic scheduler/calendar, electronic calculator, project management tool, tutorial(s) on one or more aspects of the job or software, and a database of key information. The objective is to provide the individual with access to the information and tools needed to do the job.

ELINT. Electronic Intelligence

EMI. Electromagnetic Interference

EMP. Electromagnetic Pulse

EO. Electro-optical

EOS. NASA's future Earth Observing System

EUV. Extreme ultraviolet radiation

Expert system. Typically a set of rules or a decision tree which aids an individual to make good decisions in an area where that individual is not an expert. Usually, subject matter experts are interviewed by the software developers to determine the steps the expert would use to make a particular decision. Sometimes experts are followed by note-taking observers as the experts go about formulating decisions. This often reveals that the expert was not aware of all the steps and questions used.

FALCON. Fission Activated Laser Concepts

FLOPS. Floating Point Operations per Second

FNOC. Navy's Fleet Numerical Oceanographic Center, Monterey CA

FPS. Force Protection Satellites

Galactic cosmic radiation. Energetic particles from distant stars and galaxies.

GEO. Geosynchronous Earth Orbit

GEODSSS. Ground-based Electro-Optical Deep Space Surveillance System

GOES. NOAA's Geostationary Operational Environmental Satellite

GPRC. Global Precision Response Capability

GPS. Global Positioning System

GSRT. Global Surveillance Reconnaissance Targeting

GSV. Ground Superiority Vehicles

HF. High Frequency

HUMINT. Human Intelligence

HVA. High Value Asset

HZ. Hertz

IBM. International Business Machines Corporation

ICAO. International Civil Aviation Organization

ICSW. Intercontinental Strike Weapons

IFF. Identification Friend or Foe

inclination. Angle or "tilt" of the object's orbit relative to the ecliptic plane, or Earth's orbit plane.

Information Super Highway. One of the currently popular expressions used to describe the projected network of computer/electronic connections which are to tie education, industry, government, and personal computers together so that information and questions can freely flow between all those connected on any part of the overall network. It has been popularized by and is being pushed by the current vice-president of the US.

INS. Inertial Navigation System

INSAT. India's geostationary weather satellite

interactive. Implying that the user of the software can exert some control over the software, and not just be a passive page-turner recipient. It also usually implies that part of the software design is aimed at adjusting to the needs of each individual user.

Internet. A worldwide computer network that grew out of an originally small network designed by the Department of Defense to allow rapid communication between universities, research laboratories, and military project offices.

IR. Infrared

IRCS. Infrared Cross Section

JEM. Jet Engine Modulation

JSTARS. Joint Surveillance, Targeting and Reconnaissance System

KEP. Kinetic Energy Penetrators

KEW. Kinetic Energy Weapons

kiloton or Kton. Energy equivalent to 1,000 tons of TNT (4.3 and 10^{12} Joules).

KKV. Kinetic Kill Vehicle

Lagrangian points. Points in a two body gravity system of large objects (such as the Sun and Earth) where small objects can orbit the primary body and remain almost stationary relative to the secondary body.

LANDSAT. Earth-sensing satellite managed by NASA

LCS. Laser Cross Section

LEO. Low Earth Orbit

Libration point. Point in between two planetary masses where gravitational forces of the two masses are essentially balanced

LIDAR. Laser Imaging and Ranging Device

LightSat. Light-weight satellite that can be quickly launched.

Logistics activities. Broadly encompassing all the activities aimed at providing and sustaining access to space. These include building and maintaining a space operations infrastructure and training the human resources that sustain space logistics, monitoring and reporting from space, and counterforce operations. In the SPACECAST 2020 report logistics activities include space research and

development, space system design and procurement, space launch operations, on-orbit maintenance and resupply, tracking, telemetry and spacecraft systems commanding (TT&C), de-orbit-operations, and education and training for military space operations.

long-period comets. Comet with a orbital period around the Sun greater than 20 years. Sometimes this class is divided into intermediate period comets (those with orbital periods between 20 and 200 years) and long-period comets.

LPI. Low Probability of Intercept

LWIR. Long Wave Infrared

magnitude. A number, measured on a logarithmic scale, used to indicate the brightness of an object. Two stars differing by 5 magnitudes differ in brightness by a factor of 100. The brighter the star, the lower the numerical value of the magnitude; very bright objects have negative magnitudes. The star Vega (alpha Lyrae) is defined to be magnitude zero.

main-belt asteroids. Asteroids occupying the main asteroid belt between Mars and Jupiter, sometimes limited specifically to the most populous parts of the belt, from 2.2 to 3.3 AU from the Sun.

MARV. Maneuverable Reentry Vehicle

megaton or Mton. Energy equivalent of one million tons of TNT (4.3×10^{16} Joules).

MEO- Medium Earth Orbit

meteor. The light phenomenon produced by an object experiencing frictional heating when entering a planetary atmosphere; also used for the glowing meteor itself. If particularly large, it is described as a fireball.

meteorite. A natural object of extraterrestrial origin that survives passage through the atmosphere.

METEOSAT. Geostationary weather satellite managed by the European Space Agency

MIT. Massachusetts Institute of Technology

Monitoring and reporting Activities. Those directed toward observation and orientation to reduce uncertainties, and to provide communications for the purpose of exercising command of military forces. Although omni-spectral surveillance of the planet and of space are important elements of this area of activity, others include using space and the vertical dimension for the command of forces operating in all media, communications, navigation, and for the information collection and fusion that, assisted by computational power, results in intelligence. In the area of

monitoring and reporting there are many commonalties between national security needs and systems and the systems serving the needs of business and commerce.

MRI. Magnetic Resonance Imaging

MSI. Multispectral Imaging

MSX. Midcourse Space Experiment

multimedia. A term which is commonly used to describe almost any software product which includes multiple types of media, such as color pictures, sound, and video. Multimedia applications are also typically interactive, in that the user can respond to the program and it will in turn adapt to user inputs.

NASA. National Aeronautics and Space Administration

NASP. National Aerospace Plane

NEO. Near-Earth-Object. Objects whose orbits bring them near the Earth. Specifically, Apollo, Amor, and Aten asteroids, and certain comets.

NIH. National Institutes of Health

NMR. Non-Magnetic Resonance

NOAA. National Oceanic and Atmospheric Administration

NODDS. Navy's Naval Oceanographic Data Distribution System

NORAD. North American Aerospace Defense Command

Nowcasting. Forecasting weather, for the next few minutes to a couple of hours using all immediately available weather data

NRL. Naval Research Laboratory

OBC. On-Board Computer

Omni-sensorial. Any of several optical, acoustical, or radio-frequency instruments that using interference phenomena between a reference wave and an experimental wave, or between two parts of an experimental wave to determine wavelengths, wave velocities, distances, and directions.

on-line. Generic term to describe communications or information which is transmitted or available through the use of computer modems or networks. If something resides on-line, such as an electronic bulletin board, it may have no existence other than the virtual existence in the computer.

opposition. An angle of 180 degrees between a planetary object, the Earth, and the Sun. More simply, these bodies lie on a straight line with Earth in the middle.

OPSEC. Operations Security

OSO. NASA's Orbiting Solar Observatories in the 1960's and early 1970's.

OTHB. Over-the-Horizon Backscatter Radar

perihelion. The place in the orbit of an object revolving around the Sun where it is closest to the Sun.

perturbation. For a body orbiting the Sun or a planet, the gravitational effect of a third body (e.g.,another planet) on its orbit, usually resulting in small changes or periodic fluctuations. [For comets, outgassing near the sun may also act on its orbit.]

PGM. Precision Guided Munition

Photosphere. Lowest part of Sun's atmosphere where sunspots are seen.

PME. Professional Military Education, to include any education or training courses.

POES. Polar Orbiting Environmental Satellite, managed by NOAA.

RBE. Relative Biological Effectiveness

RCS. Radar Cross Section

reconnaissance. A mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or potential enemy.

reengineering. Currently popular corporate term used to describe the act of rethinking and restructuring the processes of a company before overhauling the computer systems within that company. The lesson it seeks to teach is that if you don't go through this rethinking process, the result of the computer overhaul may just be the same mistakes and problems as before, but generated one hundred times faster.

REM. A unit of ionizing radiation in human tissue, equivalent to one roentgen of x-rays.

RF. Radio Frequency

ROE. Rules of engagement

ROSS. Reusable Operating System Software

RULLI. Remote Ultra Low Light Imaging

RV. Reentry Vehicle

S4. Structural Sensory Signature System

SAIC. Science Applications International Corporation

SAR. Search and Rescue

SAS. Situation Assessment Summary

SATKA. Surveillance, Acquisition, Targeting and Attack Assessment

SBV. Space Based Visible Experiment

semimajor axis. Half the major axis of an ellipse. For a planetary orbit, it represents the body's average distance from the Sun.

short-period comet. Comet with an orbital period around the Sun less than 20 years.

SIGINT. Signals Intelligence

SOF. Special Operations Forces

SOI. Space Object Identification

solar wind plasma. Ionized gas consisting of protons, electrons, and other heavy, energetic particles ejected from Sun's corona.

space weather. Variability of the near-Earth and interplanetary space environment.

SPATRACS. Space Traffic Control System

specific impulse. Measure of fuel efficiency.

SSN. Space Surveillance Network

SSTAR. Space Surveillance, Tracking and Autonomous Repositioning

SSTI. Space Surveillance, Tracking and Identification

STEP. Space Test Experiments Platform

surveillance. The systematic observation of aerospace, surface or subsurface areas, places, persons, or things by visual, electronic, photographic or other means.

SWCL. Short Wave Chemical Laser

SWERVE. Sandia Winged Energetic Reentry Vehicle Experiment

TAOS. Technology for Autonomous Operational Survivability

telecommunications. Includes any of the component technologies used for electronic communications over a distance typically greater than that covered by a human shout. In the context of this paper it implies two-way communications.

telepresence. Using technology to give the appearance of an individual being present at a location other than the actual location of that individual. An example would be a pilot in a sophisticated simulator which was actually controlling a real airplane 500 miles away, and providing to the pilot visual and other sensory feedback as if the pilot were actually in the cockpit looking out the windscreen and feeling the turbulence. As PME 2020 includes extensive mixing of real and artificial locations and people, many of the references to virtual reality or virtual residency will in context include traditional telepresence as an integral part.

TRIM. Tactical Reentry Impacting Munition

TT&C. Telemetry, Tracking, and Control

UAV. Unmanned Aerial Vehicle

US. United States

USAF. United States Air Force

USSPACECOM. United States Space Command

UV. Ultra Violet

VBL. Vertical Block Line

VESA. Video Electronics Standards Association

VGPO. Velocity Gate Pull Off

VHSIC. Very High Speed Integrated Circuits

virtual environment. An environment which is partially or totally based on computer generated sensory inputs.

virtual learning. The delivery of educational lessons using any of the technologies included in the expanded virtual reality which is the basis for PME 2020's virtual residency.

virtual reality. Immersion of one or more individuals in a virtual environment, with the aim of achieving the illusion that they are in a place, time, or situation different from their actual real-world location and/or time.

virtual residency. In the context of PME 2020, this term means the use of virtual reality, telepresence, and other telecommunication and computer technologies to enable the PME 2020 system to deliver education and training lessons to multiple individuals (usually in geographically-separated locations) simultaneously in a manner giving the appearance and feeling of the individuals being collocated in a traditional seminar. This virtual environment will also allow within it the use of virtual audio-visual tools such as overhead projectors, chalkboards, tape recorders, slide projectors, and multimedia computer programs.

VLWIR. Very Long Wave Infrared

WWII. World War II

WDP. Weapons Delivery Platforms

WMO. World Meteorological Organization, managed by the United Nations

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